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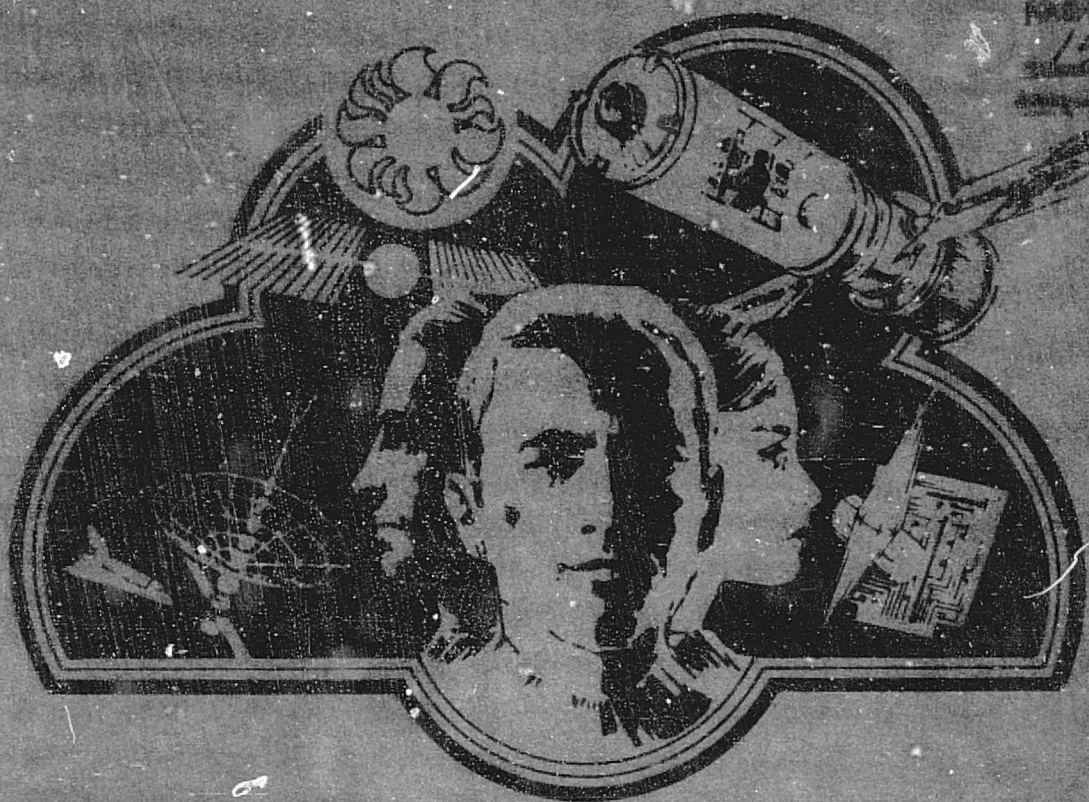
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23 FEBRUARY 1977

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## SPACE STATION SYSTEMS ANALYSIS STUDY PART 2 FINAL REPORT

**VOLUME 3**  
**Appendixes**

**Book 1**  
**Program Requirements Documentation**

(NASA-CR-151227) SPACE STATION SYSTEMS  
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**MCDONNELL DOUGLAS ASTRONAUTICS COMPANY**



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**CORPORATION**



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**SPACE STATION SYSTEMS ANALYSIS STUDY**

**PART 2 FINAL REPORT**

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**Program Requirements Documentation**

**28 FEBRUARY 1977**

**MDC G6715**

**CONTRACT NO. NAS 9-14958**

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**DR NO. MA-04**

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## PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a manned space facility capable of orderly growth with regard to both function and orbit location. The study activity has been organized into three parts. Part 1 was a 5-month effort to review candidate objectives, define implementation requirements, and evaluate potential program options in low earth orbit and in geosynchronous orbit. It was completed on 31 August 1976 and was documented in three volumes (Report MDC G6508, dated 1 September 1976).

Part 2 has defined and evaluated specific system options within the framework of the potential program options developed in Part 1. This final report of Part 2 study activity consists of the following:

- Volume 1, Executive Summary

- Volume 2, Technical Report

- Volume 3, Appendixes

- Book 1, Program Requirements Documentation

- Book 2, Supporting Data

- Book 3, Cost and Schedule Data

The third and last portion of the study will be a 5-month effort (February to June 1977) to define a series of program alternatives and refine associated system design concepts so that they satisfy the requirements of the low earth orbit program option in the most cost-effective manner.

During Parts 1 and 2 of the study subcontract support was provided to the McDonnell Douglas Astronautics Company (MDAC) by TRW Systems Group, Aeronutronic Ford Corporation, the Raytheon Company, and Hamilton Standard.

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# GLOSSARY

- Chromatography - A method of separating substances based upon their differences in selective adsorption.
- Dialysis - A process in which smaller molecules are separated from large ones in solution by diffusion through a semipermeable membrane.
- Electrophoresis - The phenomenon of migration of suspended or colloidal particles in a liquid due to the effect of an applied electric field. Separation techniques making use of this phenomenon are capable of resolving mixed protein materials effectively.
- Fixture - Equipment designed for use in constructing or assembling a functional segment of an objective element (e. g., an antenna, radiometer, or solar collector). The fixture may be a single piece of equipment or a number of items assembled to form a single piece of equipment. By its nature, a fixture is "fixed" to a larger structural element (e. g., the Space Construction Base). A fixture is made up of such items as a frame, specialized fabrication modules such as a beam cap or tube fabrication module, feed devices, robots, material storage and dispensing devices (such as strut magazines and solar blanket rolls), and various instrumentation and monitoring and control equipment.

The fixtures which have been identified in the SSSAS are as follows:

<u>Objective Element</u>	<u>Fixture</u>
SPS Test Article 1	Antenna Assembly Fixture
SPS Test Article 2	Antenna Assembly Fixture
	Solar Collector Construction Fixture
30-Meter Radiometer	Assembly Fixture

Lyophilization - The creation of a stable preparation of a substance such as a protein by rapid freezing and dehydration of the frozen product under high vacuum.

Solar Array - A blanket or panel of solar cells interconnected to act as a power source.

Solar Collector - A solar array plus solar reflectors or concentrators and associated structure.

ACS - Attitude control system

AR - Antireflective

BOL - beginning of life

BMS - Beam Mapping Satellite

BMS-C - closed loop BMS

BMS-QC - quasi-closed loop BMS

C&W - caution and warning

CES - continuous electrophoresis system

C/O - checkout

ECLSS - environmental control and life support system

ECS - environmental control system

EMC - electromagnetic compatibility

EOL - end of life

EVA - extravehicular activity

GEO - geosynchronous orbit

GPL - General Purpose Laboratory

IOC - initial operation capability

IUS - Interim Upper Stage

LWIS - living and working in space

LEO - low earth orbit

LRU - line-replaceable unit

MBL - multi-beam lens

MDSL	-	Multidiscipline Science Laboratory
MMS	-	Multimission Modular Spacecraft
OSHA	-	Occupational Safety and Health Act
OTV	-	Orbit Transfer Vehicle
RFI	-	radio frequency interference
SCB	-	Space Construction Base
SCR	-	screen controlled rectifier
SPS	-	Solar Power Satellite
SRU	-	shop-repairable unit
STS	-	Space Transportation System
TA	-	test article (TA-1L signifies Test Article 1 in LEO; TA-1G represents Test Article 1 in GEO)
TBD	-	to be determined
2D	-	two-dimensional

## 1. INTRODUCTION

The Objective Elements addressed in this Program Requirements Document (PRD) are representative of the kinds of space activities that will be supported by the Space Construction Base (SCB). They encompass the construction of solar power test articles, the development of earth survey radiometric and communications antennas, space processing of biological materials and inorganics that have scientific and commercial interest, the development and testing of optical instruments, laboratory research work in varied fields, and an evaluation of human performance in and adaptation to the space environment.

This document considers the following aspects of each Objective Element:

- A. The technical objectives, processes, activities, and tests involved in each element.
- B. The baseline mission hardware concepts for each element.
- C. The requirements imposed on the SCB by each element.

Specifically, the PRD presents for each Objective Element (1) a brief mission overview including the primary purpose and general objectives; (2) descriptions of the processes involved (where applicable), the mission hardware, the principal activities to be undertaken, the test requirements, and the principal tests; and (3) the SCB requirements including such items as special devices (e. g., fabrication modules, assembly or construction fixtures, cranes, and airlocks), power, data management and communications, waste management, environmental control, safety, and logistics.

Each Program Option is then described in terms of the Objective Elements it supports, its orbit, the general makeup of the SCB, the transportation approach, and the program schedule goals. The specific requirements that are imposed on the SCB in order to support Program Option L are given.



## 2. OBJECTIVE ELEMENT REQUIREMENTS

### 2.1 SOLAR POWER SATELLITE

The goal of the Solar Power Satellite (SPS) program is to provide a nondepletable, cost-competitive, environmentally acceptable primary energy system capable of supplying a significant portion of the world's electrical energy needs, which are expected to triple by the year 2000. The benefits to the US, as well as all the other nations of the world, obtained by achieving this goal can hardly be overstated. At its ultimate potential, a cost-competitive SPS could provide the primary solution to the growing worldwide problem of energy shortages. Even at a lower level of application, the SPS system would help slow the depletion of fossil fuels and complement the use of other alternative energy sources, such as the breeder reactor.

A space-based solar power system offers a number of advantages over a comparable terrestrial system. For instance, the solar energy available at geosynchronous orbit is 6 to 15 times that available to terrestrial systems. This increase is attributable to almost continuous sunlight, near-normal solar angle of incidence, and an absence of atmospheric attenuation or cloud interference. Since the SPS also offers the advantage of being able to transmit power directly to the region of the user's power grid, energy export is easily accomplished. Implementation of an SPS would also take advantage of the potential for use of space-manufactured solar cells.

Although it is difficult to project costs of such new power systems as the SPS, it appears that it is a viable candidate for providing a major share of the electrical power required subsequent to the year 2000.

A JSC prototype model of the SPS system has been selected for purposes of the Space Station Systems Analysis Study. While the selected model may not accurately represent the final concept, it is reasoned that the general manner in which the Space Construction Base (SCB) supports SPS development will not vary. Therefore, if the SCB facilities are defined as general-purpose equipment capable of supporting a number of construction projects, the equipment will support development of any SPS concept.

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The selected SPS prototype model concept, developed by JSC during an in-house study, is illustrated in Figure 2.1-1. Since development of the SPS construction process is a prime SCB objective, MDAC's concept for the prototype construction system is included in the figure.

Joint NASA/MDAC studies have identified six general development requirements that must be satisfied before commitment to a full-scale program can be made. These requirements are defined in Table 2.1-1. The construction development task requirements of Item 1 in the table are detailed in Table 2.1-2. This table also indicates which elements of the requirements will be satisfied by Shuttle sorties, by the SCB (and the several test articles), and by the full-scale SPS. The MDAC approach to satisfying the six development requirements is based on:

- A. The principle that space test activity must be justified when compared to possible ground test programs.
- B. An assumption that by the time the SCB is activated, definition of the favored SPS concept will be reasonably firm. (The concept of Figure 2.1-1 is presently used as an example.)

An overview of the SPS development program is presented in Figure 2.1-2. The overall SPS development program schedule and the major decision points relating to it are presented on the lower third of the figure. An overview of the proposed orbital test and demonstration program consists of some early Shuttle sortie component and subsystem development followed by construction and test of a series of test articles (1, 2, and 3) time-phased to provide an orderly and economical growth of subsystem and system technology capability.

The period of primary interest is the 1984-1987 period of TA's 1 and 2. This activity is SCB-supported and is required to develop the confidence needed to make the system development decision in early 1987. Test Article 3 is part of the system development program (Phase C) to begin about 1991. Test Article 1 will be constructed and performance-tested starting in mid-1984 and sent to geosynchronous orbit (GEO) in early 1986. This permits approximately one year of GEO testing prior to the 1987 commitment. TA-2 construction will be begun in mid-1985, and testing will occur in 1986 prior to the 1987 decision point.

**DIMENSIONS:**  
**SOLAR COLLECTOR (COMPLETED) – 27.5 KM X 5.2 KM**  
**ANTENNA DIAMETER – 1.0 KM**

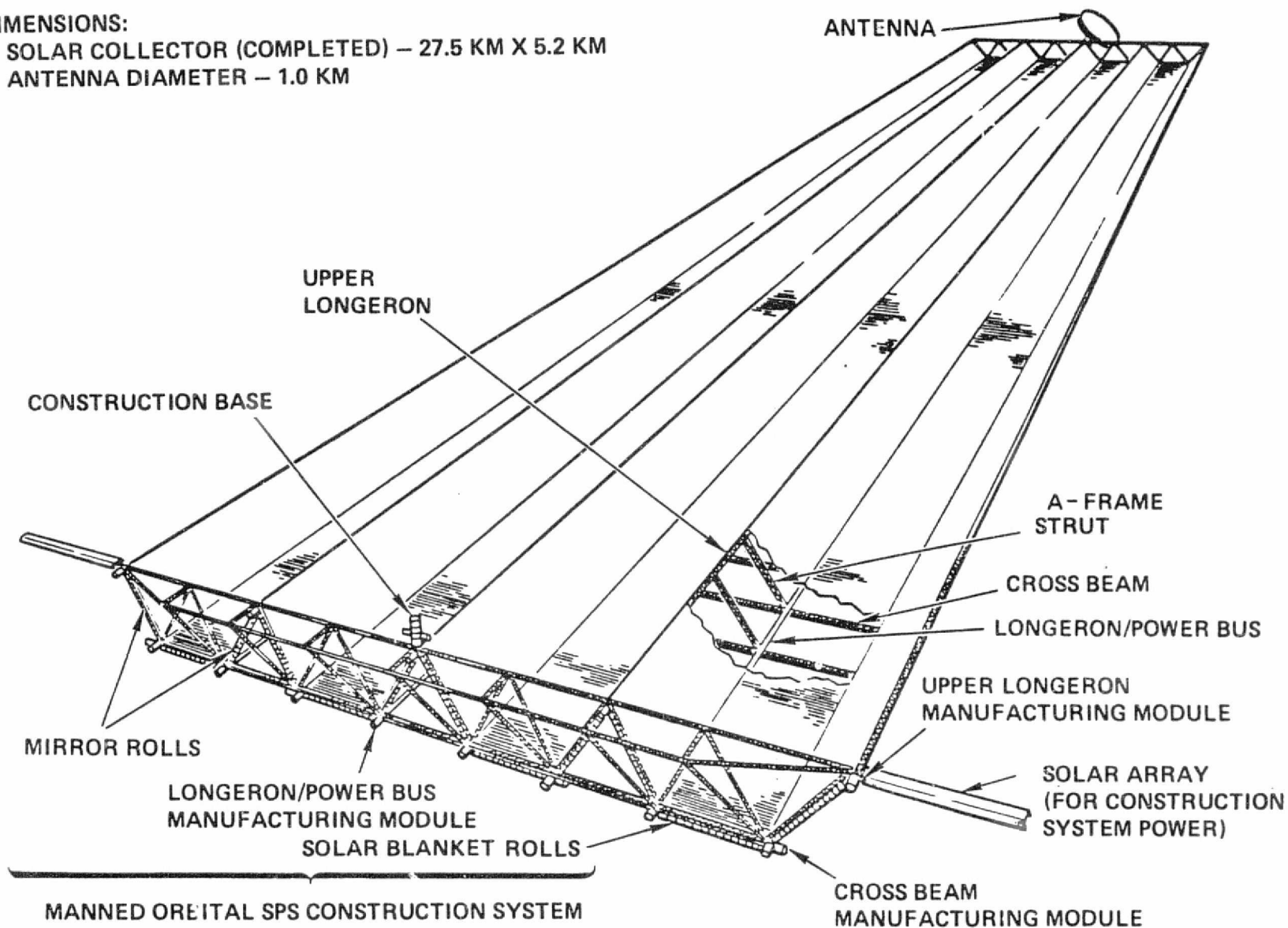


Figure 2.1-1. JSC 10-Gigawatt SPS Design Concept

Table 2.1-1

SPS DEVELOPMENT REQUIREMENTS

1. Evaluate the space fabrication/erection, control, operation, and efficiency of large structures, including structural interfaces and processes which might be used in full-scale prototypes of:
  - A. Solar collectors
  - B. Microwave antennas
  - C. Structural interfaces
2. Evaluate the technique and designs for large-scale solar energy collection and energy distribution:
  - A. 20,000 V required with associated power distribution representative of prototype or full-scale solar collectors
  - B. Simulate switching at prototypical voltage and current levels
3. Evaluate techniques and designs for large-scale microwave power transmission and phase control. Specific technical issues to be addressed include:
  - A. The interaction and potential degradation of the phase control system at GEO by the ionosphere when heated by the full-scale microwave beam. (Ionospheric heating may be simulated from the ground using high-frequency energy illuminating a region not to exceed 10 times the prototype beam width.)
  - B. Evaluate the effects on the phase control system of thermostructural distortion of waveguides and subarray structure. (Distortion results from solar environment and equipment heat dissipation.)
4. Evaluate RFI effects of the transfer by microwave of large quantities of electrical energy to earth from space, including effects of interaction with the ionosphere. Specific RFI sources/issues include:
  - A. Direct transmission of RFI from prototypical energy conversion devices (amplitrons) in the basic geometry at the subarray level (proper number of amplitrons in subarray from cascading should be included)
  - B. Switching and rotary joint sources of RFI must be evaluated
  - C. Voltage-level regulation over the full operating range must be considered
  - D. Ionosphere-induced RFI with full-scale heating of the ionosphere from ground-based sources
5. Evaluate the interactive effects of high-voltage structures and electrical components in the space plasma at LEO and GEO. Particular concerns are:
  - A. Arcing associated with full-scale voltage and conductor path lengths at LEO conditions
  - B. Spacecraft charge phenomena with full-scale breakdown lengths associated with rationally critical areas, materials, and grids projected for SPS prototypes at GEO
6. System end-to-end functional verification in space which would also address the following specific technical issues:
  - A. Thermal/structural interaction - 20 to 25 kW/m<sup>2</sup> RF for amplitron
  - B. Phase control system performance to verify overall system efficiency
  - C. Power transfer/rotary joint current density verification



Table 2.1-2

## SPS CONSTRUCTION DEVELOPMENT TASKS

Techniques and Capabilities	Requirements (per Table 2.1-1, Item 1)			Initial Development Vehicle		
	A. Solar Collectors	B. Microwave Antennas	C. Structural Interfaces	Shuttle	SCB	SPS
1. Evaluation of Space Construction of Large Structures						
A. Fabrication of truss element for substructure						
1. Materials	X	X		X		
2. Joints and joining	X	X	X	X		
3. Beam builder	X	X	X			
a. Subscale				X		
b. Full-scale					X	
B. Assembly of substructure from truss elements						
1. Joints and joining	X	X	X	X		
2. Handling of long structural members	X	X		X		
3. Alignment and rigidizing	X	X			X	
4. Handling of large structures	X	X				
a. Subscale					X	
b. Full-scale						X
C. Attachment of large-area superstructure (reflectors, solar cell blankets, antenna subarrays, conductors)						
1. Deployment	X	X			X	
2. Joints and joining	X	X	X	X		
3. Alignment	X	X	X			
a. Subscale					X	
b. Full-scale						X
D. Installation of large, active components (ball joint, ACS support modules)						
1. Joining	X	X	X	X		
2. Docking and rigidizing		X	X			
a. Subscale					X	
b. Full-scale						X

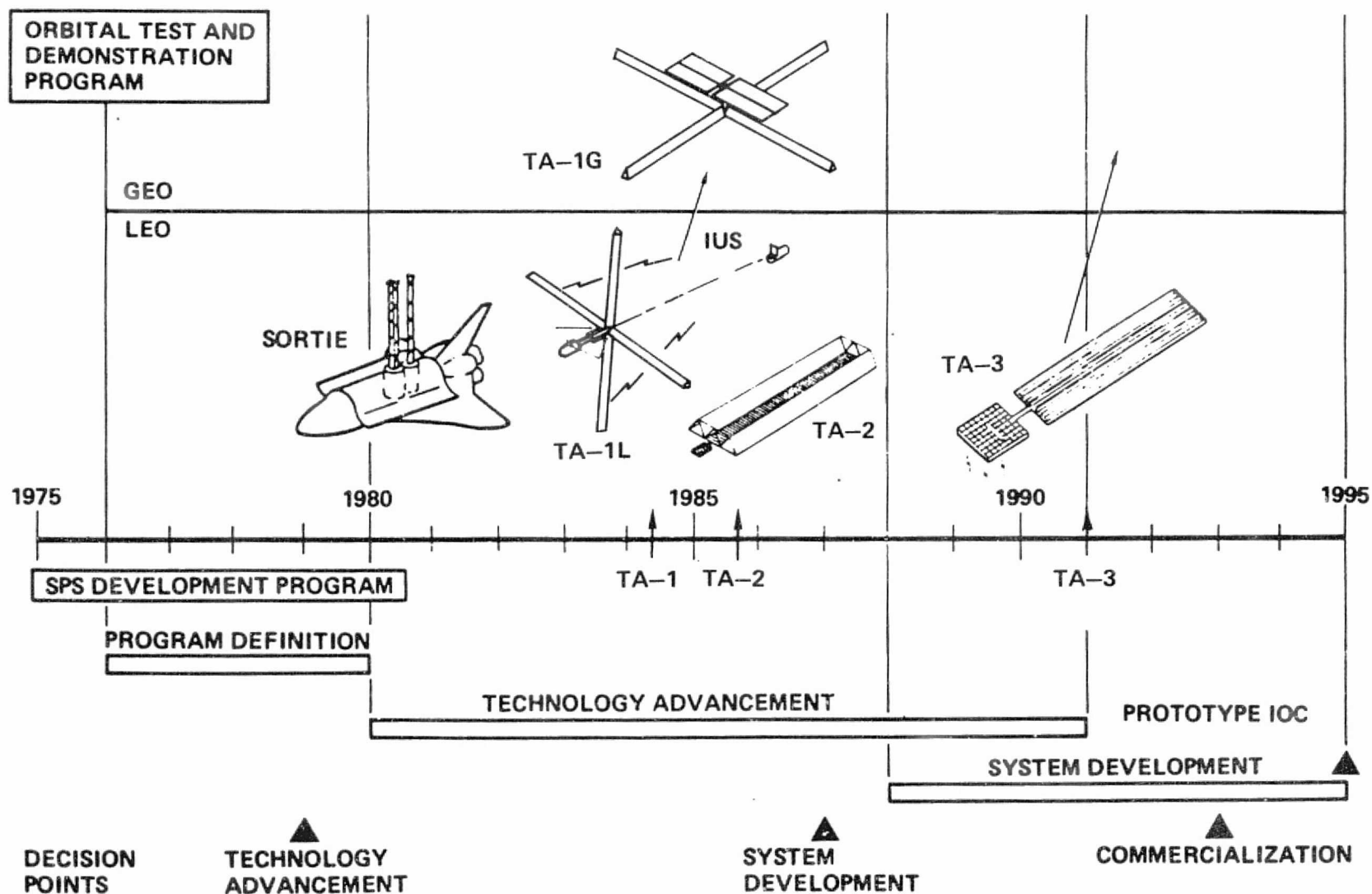


Figure 2.1-2. SPS Orbital Test and Demonstration Program

Current plans call for a four-phase development program to address the issues of Table 2.1-1. Four test articles are involved:

1. Test Article 1 in low earth orbit (TA-1L) for development of antenna construction and checkout techniques, LEO environment evaluation, and orbit-to-orbit evaluation of phase control, beam quality, and RFI
2. Test Article 1 in geosynchronous orbit (TA-1G) to evaluate GEO environment effects and measure long-term phase control through the ionosphere (heated)
3. Test Article 2 (TA-2) in low earth orbit to demonstrate the feasibility of prototypical orbital construction techniques, two-dimensional phase control, thermostructural interactions, and large-scale energy collection and transmission
4. Test Article 3 (TA-3), a "partial prototype," to demonstrate full-scale construction methods and design features

These four steps will completely satisfy the SPS development requirements. In fact, as shown in Table 2.1-3, it is believed that the first three steps will provide sufficient information to support an SPS commitment decision.

Depending on the operational mode selected, the construction and test of these test articles will require from a minimum of 16 months for TA-1L to a maximum of more than 5 years for TA-2. Throughout these periods, the SCB will serve as the "factory" for producing these structures on orbit, and will support their testing.

Table 2.1-3  
SPS TEST ARTICLE REQUIREMENTS MATRIX

Summary Development Requirements*	SCB Development Test Article		
	TA-1L	TA-1G	TA-2
1. Evaluate space construction of large structures			
A. Solar collector			X
B. Microwave antenna	X	X	X
C. Structural interfaces	P	P	X
2. Evaluate large-scale energy collection and distribution			
A. 20,000 V			X
B. Switching			X
3. Evaluate large-scale microwave transmission and phase control			
A. Ionospheric degradation of phase control system		X	
B. Thermostructural effects on phase control system	X	X	X
4. Evaluate RFI effects of energy transfer			
A. Direct transmission from amplitrans	X	X	X
B. Switching and rotary joint sources	X	P	X
C. Voltage-level regulation	P	P	X
D. Ionosphere-induced		X	
5. High voltage and space plasma interactions			
A. Arcing and leakage	X	X	X
B. Spacecraft charge phenomena		X	
6. End-to-end functional verification			
A. Thermal/structural interaction	P		X
B. Phase control system	X		X
C. Power transfer/rotary joint current density			X

P = Partial satisfaction

\*Same as those listed in Table 2.1-1 (Items 1 through 6).



## 2.1.1 SPS Test Article 1L

### 2.1.1.1 Mission Overview

The functions, configuration, and characteristics of SPS Test Article 1 in LEO (TA-1L) are summarized in Figure 2.1.1-1. TA-1L represents the precursor activity of TA-1G, which operates in an unmanned mode at GEO (see Section 2.1.2). The principal TA-1L function, in addition to fabrication, assembly, and checkout activities and LEO environment tests, is determination of microwave antenna and phase control performance. The LEO operation of TA-1 provides checkout and antenna performance calibration to be used as baseline characteristics in the evaluation of GEO operation.

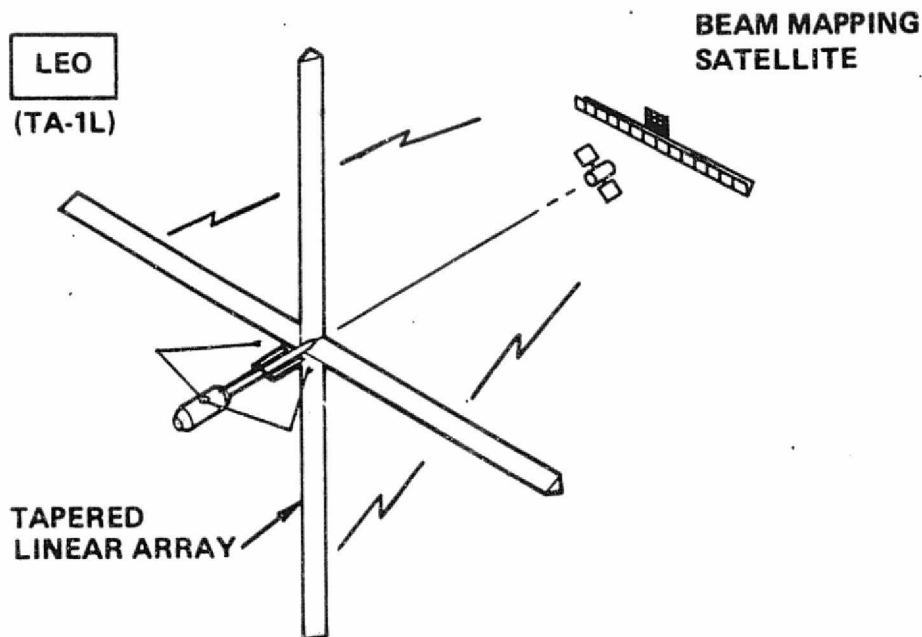
TA-1L is constructed at the SCB and tested in an attached mode as depicted in the sketch of Figure 2.1.1-1. Power is provided by the SCB.

TA-1 will operate at a nominal altitude of approximately 400 km (216 nmi) and inclination of 28.5 deg. The altitude is a compromise considering SCB drag at lower altitudes and radiation and reduced Shuttle capability at higher altitudes.

### 2.1.1.2 Mission Hardware Description

An overview of the TA-1 hardware is presented in Figure 2.1.1-1. All the TA-1G peculiar hardware will be installed during TA-1L assembly; consequently, the hardware configurations of TA-1L and TA-1G are identical, except that TA-1G operates with the solar array deployed.

Figure 2.1.1-1 shows a long standoff between the fabrication and assembly module and the antenna. The standoff permits deployment and checkout of the solar array (used in GEO operations) just prior to launch to GEO by the Interim Upper Stage (IUS). The solar array is a modified version of the SCB array. The TA-1 array has an area of 1000 m<sup>2</sup>.



#### REQUIRED LEO FUNCTIONS

##### EVALUATE SPACE CONSTRUCTION OF LARGE STRUCTURES

- MICROWAVE ANTENNA
- STRUCTURAL INTERFACES

##### EVALUATE LARGE-SCALE MICROWAVE TRANSMISSION AND PHASE CONTROL

- THERMOSTRUCTURAL EFFECTS ON PHASE CONTROL SYSTEM

##### EVALUATE RFI EFFECTS OF ENERGY TRANSFER

- DIRECT TRANSMISSION FROM AMPLITRONS
- SWITCHING AND ROTARY JOINT SOURCES
- VOLTAGE-LEVEL REGULATION

##### HIGH VOLTAGE AND SPACE PLASMA INTERACTIONS

- ARCING

##### END-TO-END FUNCTIONAL VERIFICATION

- THERMAL/STRUCTURAL INTERACTION
- PHASE CONTROL SYSTEM

##### CHARACTERISTICS FOR LEO OPERATIONS

AMPLITRON OUTPUT – 57 KW<sub>RF</sub>

ANTENNA – 123X 125.6 M CROSS

POWERED BY SCB

Figure 2.1.1-1. SPS Test Article 1, LEO

The primary sizing criteria for TA-1 is related to the need for large-aperture (narrow beam) two-dimensional (2D) phase control tests from GEO of a heated ionosphere region.

#### Antenna

The antenna for TA-1L is shown in Figure 2.1.1-2, which indicates the length of the various waveguide sections. The horizontal arm has a 2.39-m waveguide in the center while the vertical arm has two of the 2.39-m sections, one on either side of the center. The antenna is two waveguides wide, with one operating and the other for redundancy. The 46 amplitrans include the 100% redundancy. The outboard waveguides (14.36 and 28.72 m) use corporate feed with the amplitrans in the center of the waveguide. All other waveguides are fed at the end as shown in Figure 2.1.1-3.

Even though the waveguide length powered by a single amplitrans varies from 2.39 to 28.72 m for amplitude tapering purposes, a separate phase shifter is employed every 2.39 m in order to properly facilitate phase steering.

Details of the TA-1 antenna layout are shown in Figure 2.1.1-3. The left-hand figure is an expanded view of the center section of the antenna. The horizontal arm is a single 2.39-m-long waveguide (2.39 m is the distance between amplitrans in a horizontal direction). The 2.39-m waveguide is made of five standard waveguide sections, each 0.478 m long. The vertical arm has a 2.39-m section on either side of the horizontal section.

The antenna is polarized in one plane. It is necessary to have common polarization in this antenna for proper beam combination. This is accomplished as illustrated in the lower right-hand sketch of Figure 2.1.1-3, which is a blow-up of a piece of the vertical arm. The waveguides are turned on edge in the vertical arm so the 0.0498-m dimension is seen, whereas the 0.0995-m width of the waveguide is seen for the horizontal arm (waveguide cross section is 0.0498 x 0.0995 m, as appropriate for a wavelength ( $\lambda$ ) of 0.1225 m). The waveguide slots are horizontal on

# INSTALLATION

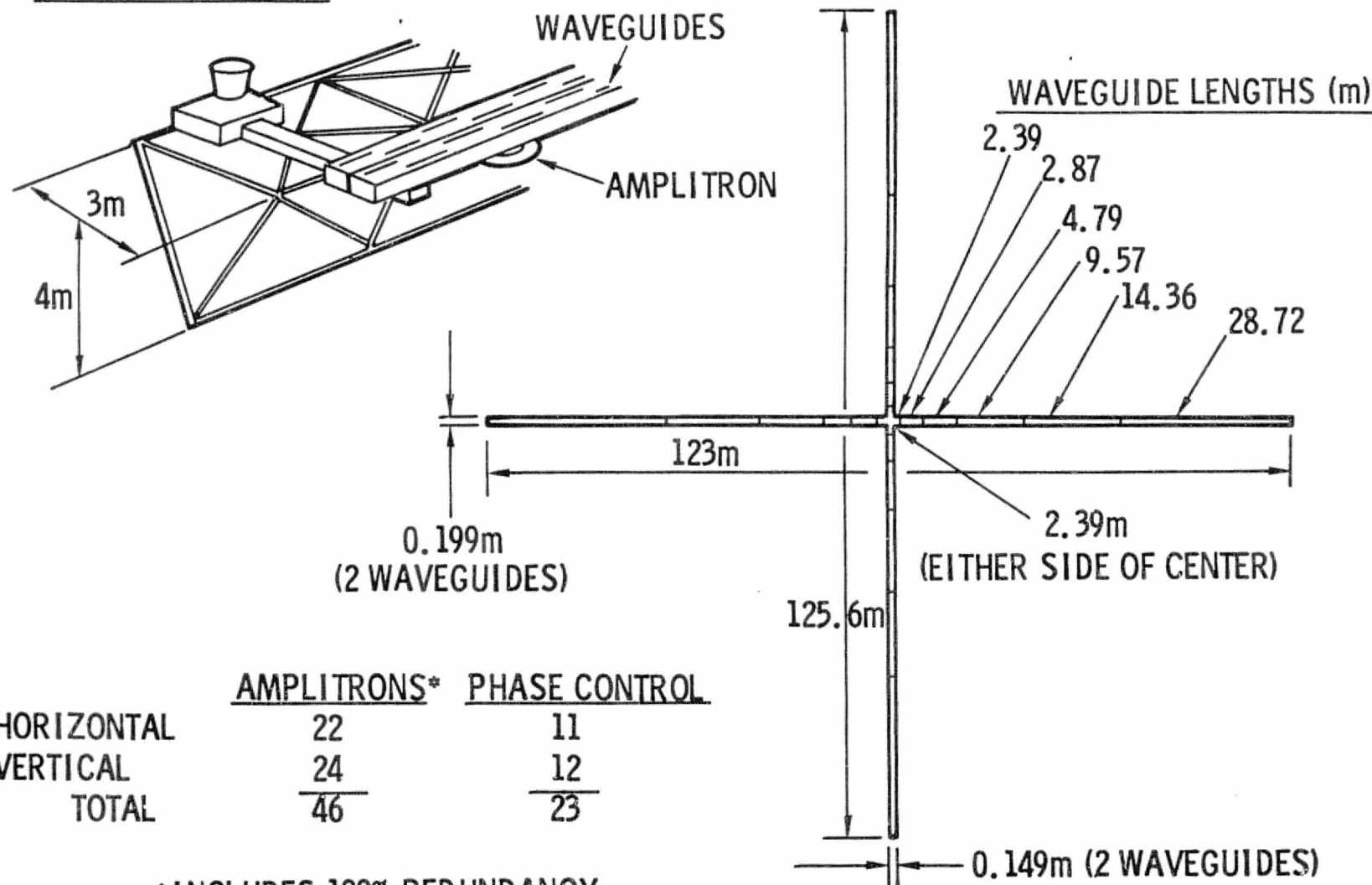


Figure 2.1.1-2. SPS TA-1L Antenna

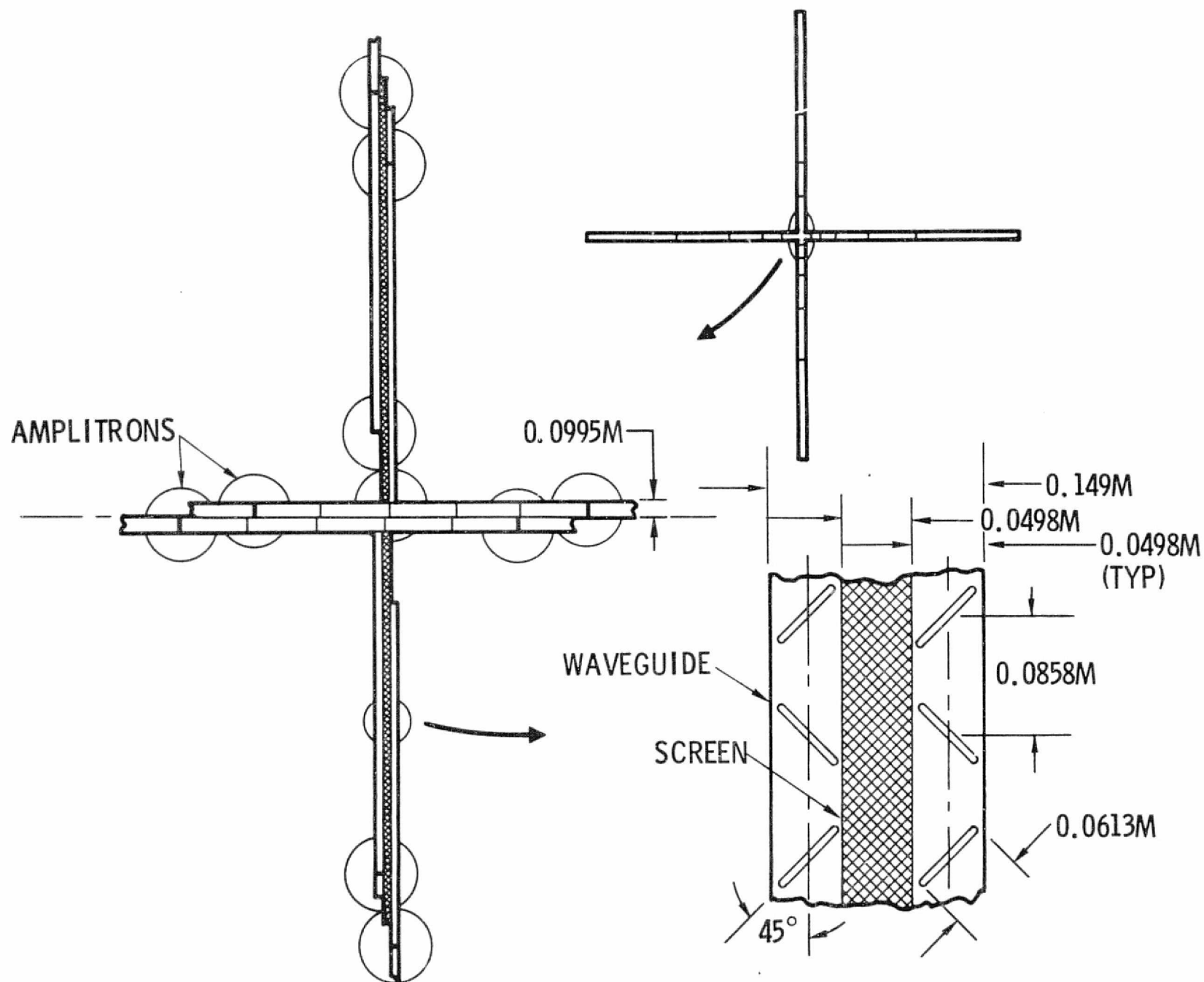


Figure 2.1.1-3. SPS TA-1L Antenna Design

the horizontal arm, and at approximately 45 deg for the vertical arm. The screen is included to provide proper spacing between slots in the event both waveguides are operated simultaneously.

A TA-1 mass summary is presented in Table 2.1.1-1.

Table 2.1.1-1  
TA-1 MASS SUMMARY

Elements	Mass (kg)
Solar Array	1,520
Microwave Antenna	2,288
Amplitrans	74
Waveguide Panels	320
Phase Control Electronics (23)	1,043
Waveguide Phase Shifters	44
Panel Leveling Device	154
Thermal Protection	64
Structure	589
Standoff Structure	502
Supporting Subsystems	431
Subtotal	4,741
Contingency (25%)	1,185
Total	5,926 kg (13,070 lbm)

The structural concept for the TA-1 antenna is depicted in Figure 2.1.1-4. \*  
The structure is a graphite/polyimide tube truss design.

\* The antenna of the figure is an obsolete configuration but the structural concept and the general arrangement depicted in Section A-A are still valid.

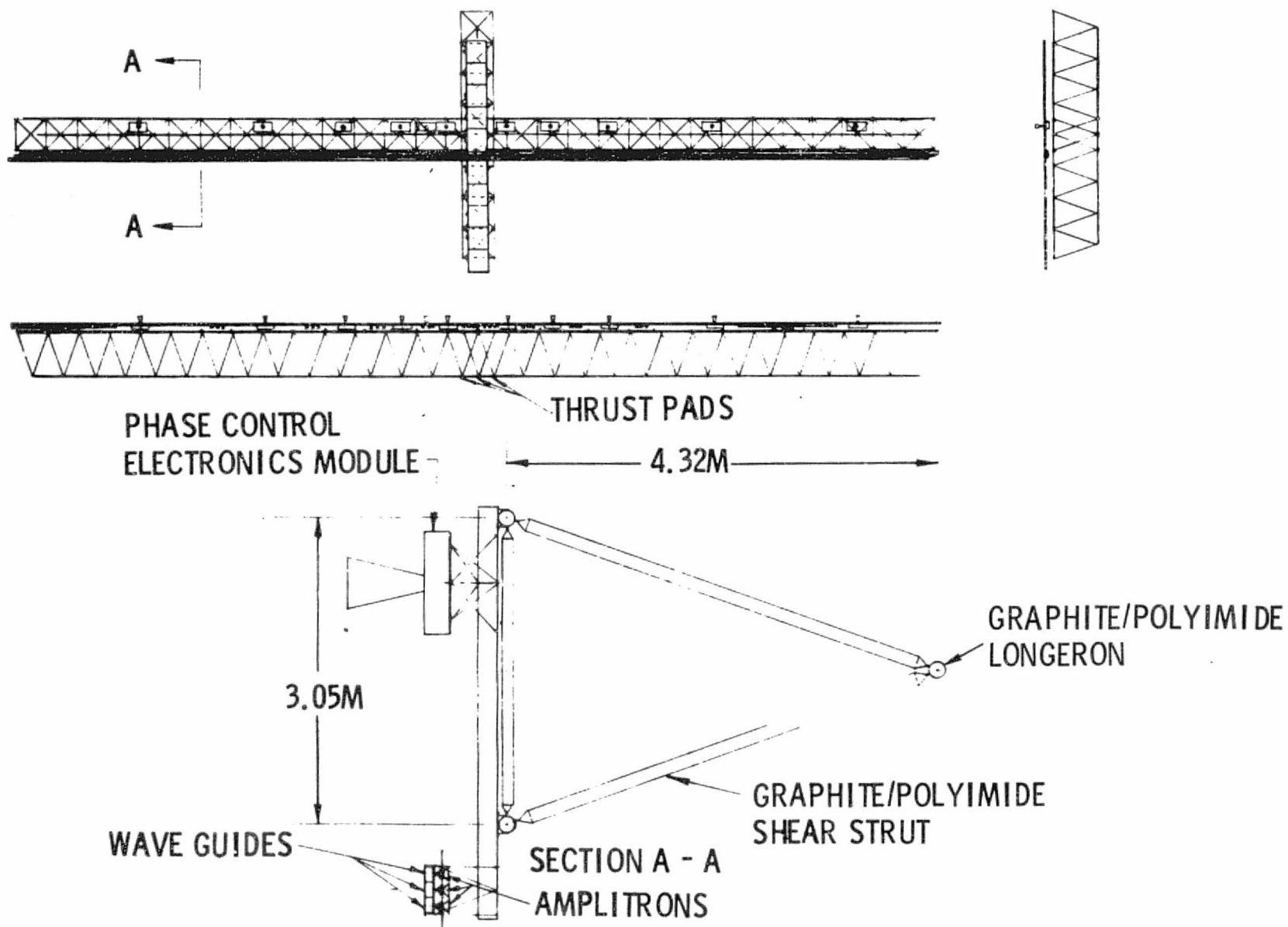


Figure 2.1.1-4. Typical SPS TA-1L Structure

### Standoff Structure

The standoff structure is located between the SCB fabrication and assembly module and the TA-1L cross antenna, as can be seen in Figure 2.1.1-1. The function of this structure basically is to provide (1) a housing for the supporting subsystems used for free-flying in GEO, (2) mounting structure for the gimbaled solar arrays, and (3) an antenna-to-SCB support structure and attachments. The portion of the structure between the SCB and TA-1 solar array attach point is a collapsible open-truss structure.

### Supporting Subsystems

The TA-1 supporting subsystems will be relatively simple since the test article is attached to the SCB. The basic functions to be accomplished include command and control and instrumentation. These functions will be accomplished by an instrumentation and signal conditioning subsystem coupled to the SCB by a data bus. These systems will be supported by power from the SCB to ensure reliable operation and continuity during eclipse periods.

### Beam Mapping Satellite

Beam mapping satellites (BMS's) will be used to map microwave power transmission antenna beam patterns and frequency content. The functions of the BMS are to (1) map microwave radiation patterns to an angle of  $\pm 5$  deg about the TA-1 antenna axis, (2) evaluate RFI to an angle approaching  $\pm 180$  deg from the antenna axis, and (3) provide the phase control system pilot beam when required.

The BMS operates in the same orbit as the SCB at the near edge of the antenna far field where the beam is properly formed. Mapping is accomplished by electronically sweeping the beam past the satellite. Instrumentation consists of field strength measuring devices and a frequency spectrum analyzer. The BMS also contains (1) a microwave pulse transponder for range (to test article)



measurement, (2) an optical beacon (high intensity strobe light) for accurate measurement of the satellite's angular position from the TA-1 antenna geometric centerline, and (3) a telemetry system.

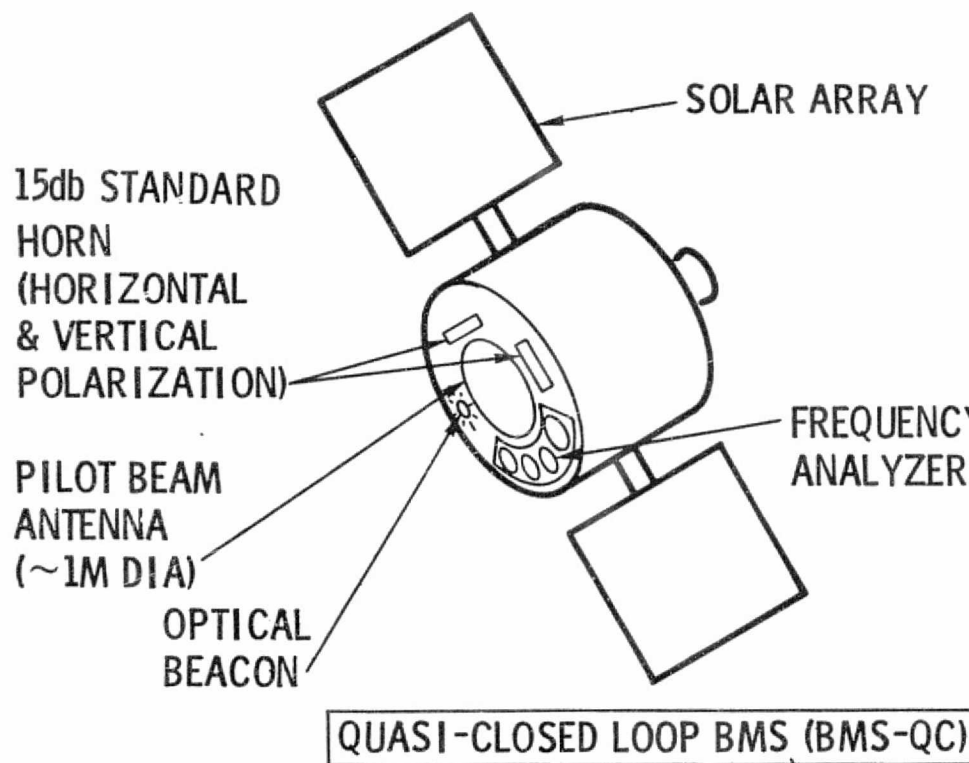
Spacecraft systems include (1) an attitude control system to allow pointing of body-mounted sensors and beacons, (2) a propulsion system to allow station-keeping and maneuvering, and (3) a command and control system that allows the beam mapping satellite to be controlled from the SCB.

Two kinds of beam mapping satellites will be used to test TA-1. They are shown, with their functions, in Figure 2.1.1-5. (These same satellites will be used to test TA-2.)

BMS-QC (quasi-closed loop) provides the pilot pulse via the pilot beam antenna (~1 m in diameter). The overall satellite is on the order of 2 m in diameter and 2 m long. The power requirement is expected to be a few hundred watts. The BMS-QC operates 258 km from the TA-1 at the near edge of the antenna far field. It maps the TA-1 beams using two 15-db standard horn antennas, one for horizontal and one for vertical polarization. The optical beacon serves as a target for the TA-1 optics system to provide array normal line-of-sight data with respect to the BMS line of sight. The frequency spectrum analyzer is depicted by a series of antennas for various frequencies to evaluate out-of-band RFI.

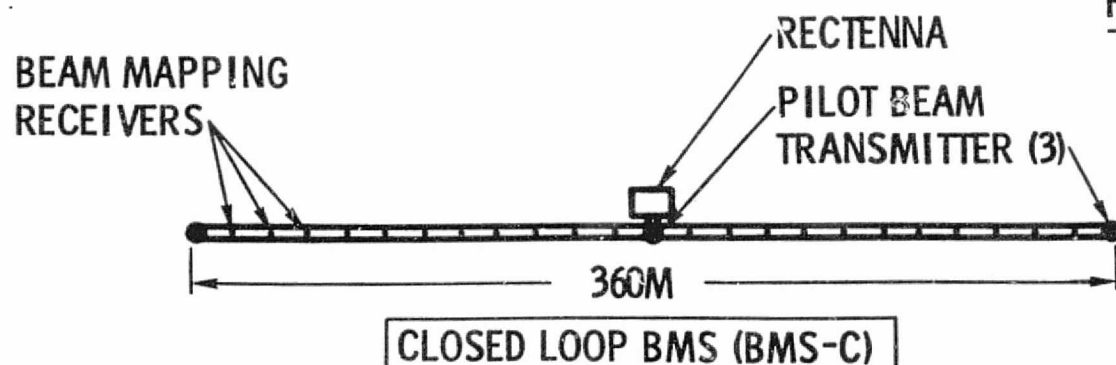
BMS-C (closed-loop) consists of a rectenna and a 360-m-long structure with three pilot beam transmitters (one in the middle and one at either end) and a series of beam mapping (field strength measuring) receivers. The BMS-C can map the beam at the same time one of the pilot beams is operated; therefore, it can simulate the SPS operation more closely than the BMS-QC can. (The use of BMS-QC requires the recording of pilot beam signals for slightly delayed replay.) BMS-C beam mapping is at ranges of 129 km (far edge of the near field) and 258 km (near edge of the far field.)

The rectenna used for power transfer demonstration is approximately 15 x 20 m in size.



### FUNCTIONS

1. BEAM MAPPING MEASUREMENTS
2. RFI MAPPING MEASUREMENTS
3. PROVIDE PILOT PULSE SOURCE



### FUNCTIONS

1. CLOSED LOOP BEAM MAPPING
2. TA-2 POWER TRANSFER

Figure 2.2.1-5. TA-1 and TA-2 Beam Mapping Satellites

The BMS-QC is expected to weigh less than 1000 kg and require on the order of a few hundred watts of peak electrical power, which is provided by an oriented solar array and battery system. It is expected that an existing unmanned satellite can be adapted to be a suitable carrier vehicle. In particular, communications satellites generally have both the propulsion and command and control capabilities required by the BMS-QC. The required propulsion capability is 500 m/sec. It would also appear that this vehicle will be small enough to be included as cargo on a regular Orbiter logistics flight, and since the BMS always operates in close vicinity to the SCB, it could be serviced on orbit by the Shuttle as part of an SCB mission.

Another leading candidate for the BMS-QC carrier vehicle is the Multimission Modular Spacecraft (MMS) currently in development by NASA. The MMS has a distinct advantage in that it is designed to be retrieved, refurbished, and relaunched by the Space Shuttle.

The BMS-QC, which is similar to the satellite required for the Earth Services antennas, does not place major technical requirements on the SCB. A common carrier vehicle with special payload instrumentation for each of the applications is tentatively planned.

#### 2.1.1.3 Activity and Test Descriptions

This section summarizes TA-1 construction activities and operations, test requirements and descriptions, and SCB support requirements. The technical objectives of TA-1 were presented earlier in Table 2.1-1 and briefly summarized in Figure 2.1.1-1.

##### Activity Descriptions

Figure 2.1.1-6 summarizes the construction technique for TA-1L. The antenna consists of panels made up of waveguide and amplatron sections fabricated on the ground and attached to a support structure fabricated on orbit. The support structure is constructed entirely from graphite polyimide tubes fabricated on orbit by a composite tube fabrication module. The tubular longerons for the arms of the antenna are fabricated first and inserted in the assembly fixture as shown in Figure 2.1.1-6. The fixture employs a

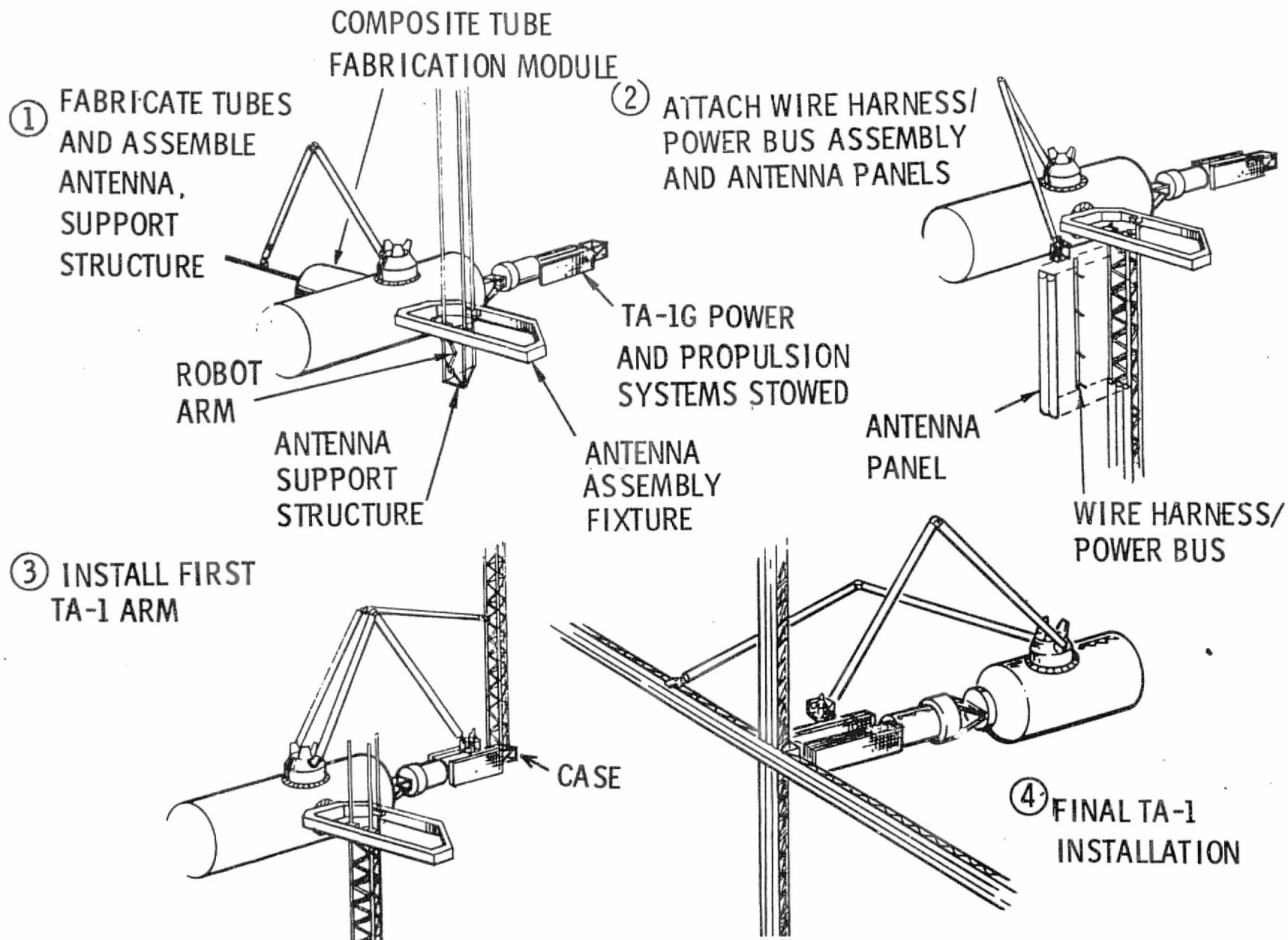


Figure 2.1.1-6. SPS TA-1L Assembly Sequence

synchronized automatic system to feed the longerons past three standard industrial robots. These programmed robots place the tubular support struts in position against the longerons where they are bonded.

Periodically, support structure assembly is stopped and the wire harness and power bus assembly and antenna panels are attached by EVA. As each arm of TA-1L is finished, it is removed by crane and transferred to the preassembled case (shown in Figure 2.1.1-6) on the end of a ground-delivered standoff structure for final installation by EVA.

Operational analysis of TA-1 construction resulted in a definition of the major steps (summarized on Figure 2.1.1-7) involved in construction. Each step was examined and time in terms of work shifts (at an average of 3 men per shift) was determined. The most time-consuming tasks were found to be installation, checkout, certification of the tooling, and assembly and installation of the four arms of the 123 x 125.6-m antenna. Activities involving EVA (primarily the installation of antenna components) are time-consuming. The resulting assembly time will be 80 shifts, each averaging 3 men.

#### Test Requirements

TA-1L test requirements stem from the SPS development requirements shown previously in Tables 2.1-1 through 2.1-3. The test requirements specifically applicable to TA-1L are indicated in Table 2.1-3.

TA-1L must utilize and demonstrate prototype components, processes, voltages, power densities, and other concepts to the maximum extent possible. These considerations indicate that the requirements for end-to-end functional verification (particularly of phase control system performance) and evaluation of space construction can best be met by constructing a reasonably large test article such as a crossed, tapered linear array microwave antenna. In this process, a number of other test requirements can be met, as indicated in Table 2.1-3.

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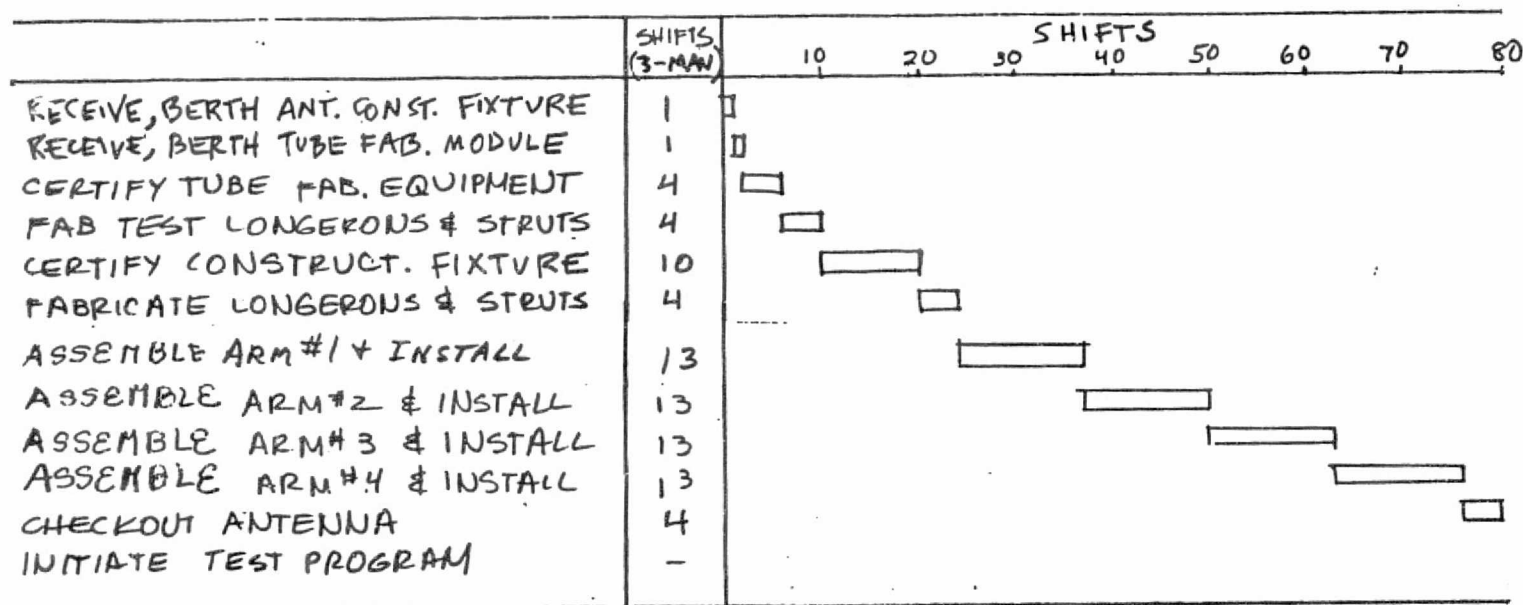


Figure 2.1.1-7. SPS TA-1 Construction Timeline

The matrix of Table 2.1.1-2 shows what TA-1L tests will be required to satisfy the six development requirements established in Section 2.1 (see especially Table 2.1-1). The test requirements and the rationale for test selection are discussed below under numbered headings that correspond to the numbered development requirements of Table 2.1.1-2. The tests themselves are discussed in a subsequent section titled Test Descriptions. Again, the subsection headings are numbered to correspond with the numbered subjects in the Test Descriptions column of Table 2.1.1-2.

#### 1. Space Construction of Large Structures

A primary objective of antenna structure testing is to develop data on the feasibility and cost of constructing very large structures on orbit. The antenna structure is critical since the dimensional stability requirements are exceptionally stringent and large transient temperature gradients are expected. Since the antenna structure uses thin wall composite tubing — with thermal expansion coefficients near zero — similar to that required for the SPS model, the structure should be constructed in orbit to develop the necessary data.

Space construction-related test requirements largely involve initial calibration and an evaluation of the quality and performance of the space-constructed product in the LEO environment; specifically, as-built accuracy and mechanical alignment, thermal stability, and structural dynamics (inertial and thermal) are of interest. Specific measurements of interest are indicated in Table 2.1.1-2.

Construction of a large microwave transmission system that must retain high-power transmission efficiency and hold spurious radiation, leakage, and side-lobe energy to an absolute minimum imposes severe mechanical and electrical tolerances on system assembly, alignment, and calibration. Economical construction of such a system in space requires evaluation of special test equipment, fixtures, and time-consuming subassembly alignment and calibration procedures. Accordingly, the proposed space construction methodology will be verified by constructing TA-1 in LEO before finalizing the fabrication, assembly, alignment, and calibration procedures and fixtures for constructing TA-2, TA-3, and the full-scale SPS microwave power transmission system in space.

Table 2.1.1-2

## TA-1L DEVELOPMENT AND TEST SUMMARY

Test Descriptions (Tests and Variables)	SPS Development Requirements (Reference Table 2.1-3)					
	1. Space Construction of Large Structures	2. Energy Collection and Distribution	3. Microwave Transmission and Control	4. RFI Effects	5. High Voltage and Space Plasma Interaction	6. End-to-End Functional Verification
1. Space Construction						
A. Longeron and strut structure fabrication	X					
B. Antenna structure assembly	X					
C. Structure, waveguide sections, and power module assembly	X					
2. Antenna Alignment, Calibration, and Test						
A. Assembly, alignment, and calibration procedures verification	X					
B. Voltage standing wave ratio measurements	X					
C. Mechanical alignment test	X					
D. Relative phase measurements between critical points	X		X			X
E. DC power	X		X		X	
3. Radiation Pattern						
A. Pointing angle			X	X		X
B. Temperature			X	X		X
C. DC power			X	X		X
D. Frequency			X	X		X
4. Efficiency						
A. Pointing Angle						X
B. Temperature						X
C. DC power						X
D. Frequency						X
5. Pointing Accuracy						
A. Pointing angle			X			X
B. Temperature			X			X
C. DC power			X			X
6. Stability						
A. Pointing angle	X					X
B. DC power	X					X
7. Spurious Radiation						
A. Temperature				X	X	X
B. Frequency				X	X	X
C. Spherical look angle				X	X	X



## 2. Energy Collection and Distribution

TA-1L will receive power at low voltage from the SCB. TA-1G will get its power from a modified SCB array also operating at low voltage. This solar collector is not representative of a prototypical SPS collector. No requirements exist, therefore, for TA-1 to demonstrate large-scale energy collection and distribution.

## 3. Microwave Transmission and Control

Evaluation of the microwave power transmission, beam forming, and beam steering capability in a benign space environment requires static main lobe pattern measurements and dynamic pointing accuracy measurements, supplemented by phase control and power data from appropriate test points. In order to separate the beam forming and beam steering phase control problems, the pattern tests must be conducted under both steered and nonsteered conditions.

## 4. RFI Effects

The RFI effects of the SPS that must be evaluated to determine environmental impact and corrective action are separated into in-band and out-of-band spurious radiations. The in-band power (2.45 GHz) is normally ignored in a transmission system. However, due to the extremely high power levels of the SPS, spurious radiation through antenna side lobes and grating lobes and leakage from microwave components may exceed the off-frequency rejection capability of other S-band equipment. The out-of-band spurious radiation (e. g., harmonics, noise, and arcing) must also be thoroughly evaluated over the frequency spectrum of interest at all hemispheric look angles.

To evaluate the in-band RFI (2.45 GHz) effects, spherical radiation patterns must be obtained under various beam steering, temperature, and power conditions since these factors have a major impact on the antenna side lobe and grating lobe structure.

Evaluation of the out-of-band RFI effects requires measurements of field strength across the spectrum and spherical mapping of the measured spectral density.

## 5. Space Plasma Effects

The arcing and leakage associated with high-voltage structures and components will be evaluated during the RFI, calibration, and power testing described above to determine the extent of the arcing and leakage and the corrective action needed.

## 6. End-to-End Functional Verification

The overall system functional performance will be verified over the range of LEO environmental conditions, and data will be collected to predict TA-1G performance and SPS performance and design solutions.

To maintain radiation efficiency and minimum side-lobe levels from the antenna requires that phase integrity be retained between radiating slots on the array. Since the waveguide propagation velocity is sensitive to temperature and the amplitron phase shift is sensitive to temperature, frequency, and power, operation in the space environment (including earth shadowing) with a power-weighted aperture imposes severe design requirements in order to maintain frequency and phase integrity of the antenna alignment. Design verification in a space environment of the frequency-phase sensing and control circuits is required to minimize pattern degradation. The verification will include monitoring the temperature gradients and the corresponding spread in resonant frequency (phase) across the array in order to evaluate the uncompensated defocusing effects applicable to the full-scale array.

Verification of the mechanical steering accuracy obtainable over the entire range of environmental conditions in space is necessary to ascertain the electronic steering limits over which specified performance is required. The electronic steering accuracy and radiation efficiency as a function of off-boresight steering conditions will be determined to evaluate the adequacy of the system design and establish necessary upgrades.

### Test Descriptions

The tests to be conducted in response to the test requirements noted in the preceding section are treated briefly in this section. These descriptions reflect the requirements summarized in Table 2.1.1-2.

## 1. Space Construction

The test phase on all construction equipment occurs during its checkout and certification prior to its use in constructing mission hardware. Table 2.1.1-3 outlines test procedures. It should be noted that while these are written in series form, they would be met in a single "all up" test procedure. This form of test is considered feasible since all components will have been thoroughly tested prior to erection in space.

The construction procedures and productivity will be evaluated by measuring key performance parameters (e. g., crew time for specific operations) while constructing the TA-1L antenna.

The dimensional accuracy of the completed antenna is of primary interest. However, measurement of the antenna to the accuracy desired will be difficult since the structure will be in constant dynamic motion. Isolation of the dynamic motion is further complicated since it will occur because of both cyclic inertial loads (attitude control system) and thermal loads (90-minute light/dark cycle). Thus determination of the isothermal load-free as-built shape requires inertial and thermal instrumentation as well as accurate determination of shape — and all measurements must be time-correlated. This instrumentation will, however, allow complete measurement of structural dynamics. A summary outline of the approach to evaluating the alignment and dynamic shape aspects of space construction and large structures follows:

- A. Optical/photographic determination of shape as a function of time
- B. Sufficient temperature sensors to allow estimate of temperature distribution in beam caps
- C. Sufficient inertial instrumentation to allow estimate of dynamic inertial loads
- D. Sufficient strain gages to evaluate stress/strength characteristics
- E. Test procedures that include holding the antenna in different fixed attitudes for several orbits

Table 2. 1. 1-3

TA-1 ANTENNA ASSEMBLY FIXTURE CHECKOUT  
AND CERTIFICATION TEST OUTLINE

- 
- I. Truss Assembly
    - A. Test both robot's ability to place truss members in all positions (fixed beam caps).
    - B. Test all attach heads by passing truss/cap junctions through head (beam caps in motion).
  - II. Control System
    - A. Test intrabeam closed loop control system by assembling short lengths of structure. Introduce artificial error signals to check response.
  - III. Salvage and Repair Procedures
    - A. Develop and test procedures for repair of assembly fixture failures.
- 

2. Antenna Alignment, Calibration, and Test

The proposed antenna consists of 206 slotted waveguide radiators 2.39 m long formed into vertical and horizontal subarrays of horizontal slotted waveguide sections employing a series-parallel amplification-feed network. For proper operation under non-beam-steering conditions, each of these 206 waveguide radiators must be energized in phase at the resonant frequency of the slotted radiators. Since the radiator resonant frequency is environment-dependent and the amplifier phase shift is environment-, frequency-, and power-sensitive, automatic phase sensor and control electronics must be employed and evaluated. Consequently, the calibration and alignment procedures used for this equipment are critical and the techniques and equipment needed to perform this task in space require verification. In addition, the calibration and alignment procedures for the phase-steering sensors and controls need verification under space conditions.

Maintaining radiation efficiency and minimum side-lobe levels from the antenna requires that phase integrity be retained between each radiating slot on the array to the accuracy required by efficiency and RFL. Since the wave-guide propagation velocity is temperature-sensitive and the amplatron phase shift is temperature-, frequency-, and power-sensitive, operation in the space

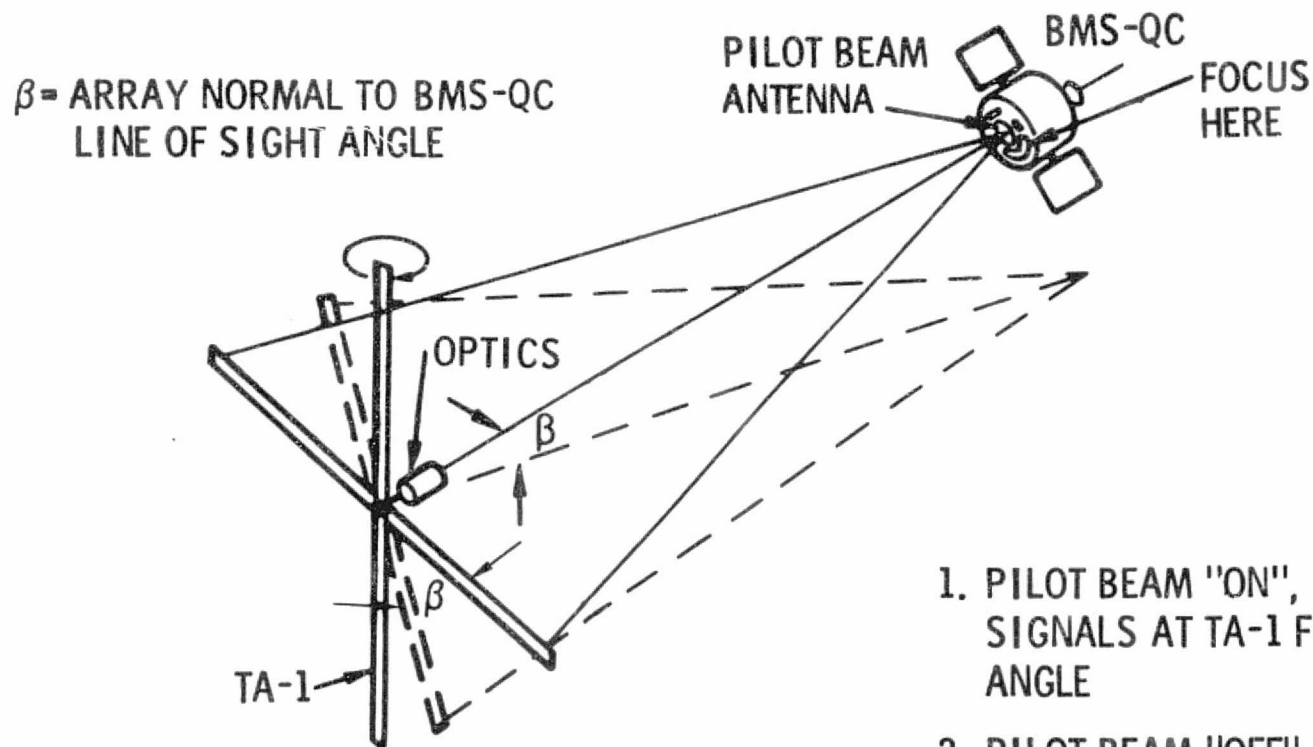
environment (including earth shadowing) with a power-weighted aperture imposes severe design requirements in order to maintain frequency and phase integrity of the antenna alignment. Design verification in a representative space environment is required on the frequency-phase sensing and control circuits to assure acceptable pattern degradation. This verification will include monitoring the temperature gradients and the corresponding spread in resonant frequency across the array in order to evaluate the phase correction as well as the uncompensated defocusing effects applicable to the full-scale array.

### 3. Radiation Pattern

The main lobe and hemispherical side lobe radiation patterns of Test Article 1 will be obtained using either of two Beam Mapping Satellites (BMS-QC and BMS-C) operating in antenna pattern test range configurations. The BMS-QC operates in the same orbit as the SCB at a range of 258 km from TA-1 at the near edge of the antenna far field where the beam is properly formed. The co-orbital BMS instrumentation will determine the two polarization power levels and telemeter these data to the SCB in real time. Correlation of these data with TA-1 optical instrumentation as the array is rotated will create the desired antenna patterns.

The BMS's will support the testing needed to help satisfy appropriate TA-1 development requirements. For a matrix of these development and test requirements, see Table 2.1.1-2. The BMS-QC beam mapping test procedure is illustrated in Figure 2.1.1-8. The solid line between the center of TA-1 and the satellite represents the geometric normal to the TA-1 antenna. Operation of the BMS-QC pilot beam steers the beam electronically toward the satellite and focuses the beam on it, as depicted in the figure by the solid lines from the ends of the antenna to the satellite.

The first of two main BMS-QC test procedures (pilot beam on) records the pilot beam signals (phase angle) for each antenna subarray while steering and focusing. The recorded phase-angle signals will include, for example, compensation for TA-1 antenna distortion.



1. PILOT BEAM "ON", RECORD PILOT BEAM SIGNALS AT TA-1 FOR FIXED STEERING ANGLE
2. PILOT BEAM "OFF", PLAY BACK RECORDED SIGNALS TO MAINTAIN FIXED STEERING ANGLE
3. ROTATE TA-1 THROUGH ANGLE  $\beta$  & RECORD FIELD STRENGTH IN BMS-QC
4. REPEAT FOR VARIOUS STEERING ANGLES

TEST ITEM	RANGE (km)	$\beta$ (DEG)
1. TA-1 BEAM MAPPING	258	$\pm 5$
2. TA-2 BEAM MAPPING	3.4	$\pm 10$
3. TA-1 & TA-2 RFI	1-258	$\pm 180$

Figure 2.1.1-8. Beam Mapping Test Procedure

The second procedure (pilot beam off) involves the playback of the recorded signals to maintain the focus and steering line of sight while rotating the TA-1 antenna through an angle of  $\pm\beta$  (rotation through an angle  $\beta$  about the vertical arm to the dotted position). This rotation sweeps the beam past the BMS-QC, which measures field strength, to produce data for a beam plot that represents a "slice" through the beam for a given beam steering angle.

The procedure discussed above is repeated for various electronic beam steering angles, which are obtained by rotating the antenna through some angle and electronically focusing the beam on the BMS-QC with the pilot beam on. The appropriate data are recorded for playback to "freeze" the pattern while sweeping through  $\pm\beta$  for the next "slice."

It is assumed that  $\beta$  and the steering angle are both in a single horizontal plane; this is a simplified representation of a multiplane situation, and the same approach is used in a number of planes.

The out-of-band RFI is measured at angles of  $\pm 180$  deg about the antenna by putting the BMS-QC in an elliptical orbit so it traces a path around the SCB. Out-of-band RFI is measured at approximately 1 km while in-band RFI is measured at ranges up to the 258 km.

The BMS-C can map the beam at the same time one of the pilot beams is operated; therefore, it can simulate the SPS operation more closely than the BMS-QC can. (The use of BMS-QC requires the recording of pilot beam signals for slightly delayed replay.) BMS-C beam mapping is at ranges of 129 km (far edge of the near field) and 258 km (near edge of the far field).

At 129 km, the 360-m length of the BMS-C permits TA-1 beam mapping of (1) one-half the main lobe and approximately two lobes on one side when one of the end pilot beam transmitters is operating, and (2) the main lobe and approximately half of each of the two first side lobes using the center pilot

beam transmitter. A three-dimensional beam map can be obtained by rotating the BMS about the test article-to-satellite line of sight to various angular positions, then repeating the test at each position.

#### 4. Efficiency

Efficiency data will be obtained by instrumenting the TA-1 microwave system to record voltage and power at the prime power input and selected critical points throughout the power transmission system. These data are then correlated by analyzing the corresponding radiation patterns and received power-level data.

#### 5. Pointing Accuracy

Static pointing accuracy is obtained by data reduction on the radiation pattern tests under various steering conditions off array normal. However, verification of these data under dynamic steering conditions will be accomplished by activating the pilot pulse system and mechanically performing a slow raster scan of the array as the pilot pulse subsystem maintains beam alignment. The recorded phase commands at the array and power level variations from the BMS-QC, when corrected for antenna gain variations, will be translated into pointing error and compared with the static error data.

#### 6. Stability

The TA-1 will be instrumented to measure and record deviations in the transmitter frequency over the range of temperature and dc power conditions imposed by the space environment. These data will be correlated with the radiation pattern and efficiency data to ascertain their contribution to pointing angle error and power transmission efficiency.

#### 7. Spurious Radiation

In addition to the side lobe and grating lobe data obtained from the hemispherical pattern test data, field strength data on arcing, noise, and harmonics will be obtained from BMS-QC instrumentation. These data must be supplemented with TA-1 field-strength data to establish any EMC problems with the SCB electronics.



The system will be checked out initially using minimum allowable voltage; then the voltage will be slowly increased for full-power operating conditions while monitoring for arcing or excessive leakage.

#### 2.1.1.4 Space Construction Base Requirements

The requirements imposed on the SCB by TA-1L and its operations are summarized in this section.

#### Special Devices

##### Antenna Assembly Fixture

The function of the TA-1 antenna assembly fixture is to demonstrate to the maximum practical extent the automated assembly of prototypical composite structural components (graphite/polyimide thin wall tubing) in a continuous-flow process.

The automated antenna assembly fixture which would be used for both TA-1 and TA-2 is shown in Figure 2.1.1-9. The figure shows assembly of the TA-2 antenna structure. In this mode, it consists of seven tube feeds positioned on a jig frame so that the antenna longerons can be simultaneously deployed. Strut attach fittings are thermally bonded to the longerons by a device immediately downstream of each tube feed. Three programmed robots, mounted on the fixture frame between the upper four longerons, place the tubular struts against these fittings where they are attached by thermal bonding or hollow rivets.

The use of adjustable positions for the robots and longeron tube feed guides (together with interchangeable parts for different longeron cross sections) allows the fixture to be adapted to the TA-1 antenna truss as shown in Figure 2.1.1-10. This entire fixture is transported as a fully assembled entity that occupies approximately two-thirds of the Shuttle cargo bay. The berthing port shown in Figure 2.1.1-9 allows it to be attached to the construction base. A mass summary is presented in Table 2.1.1-4.

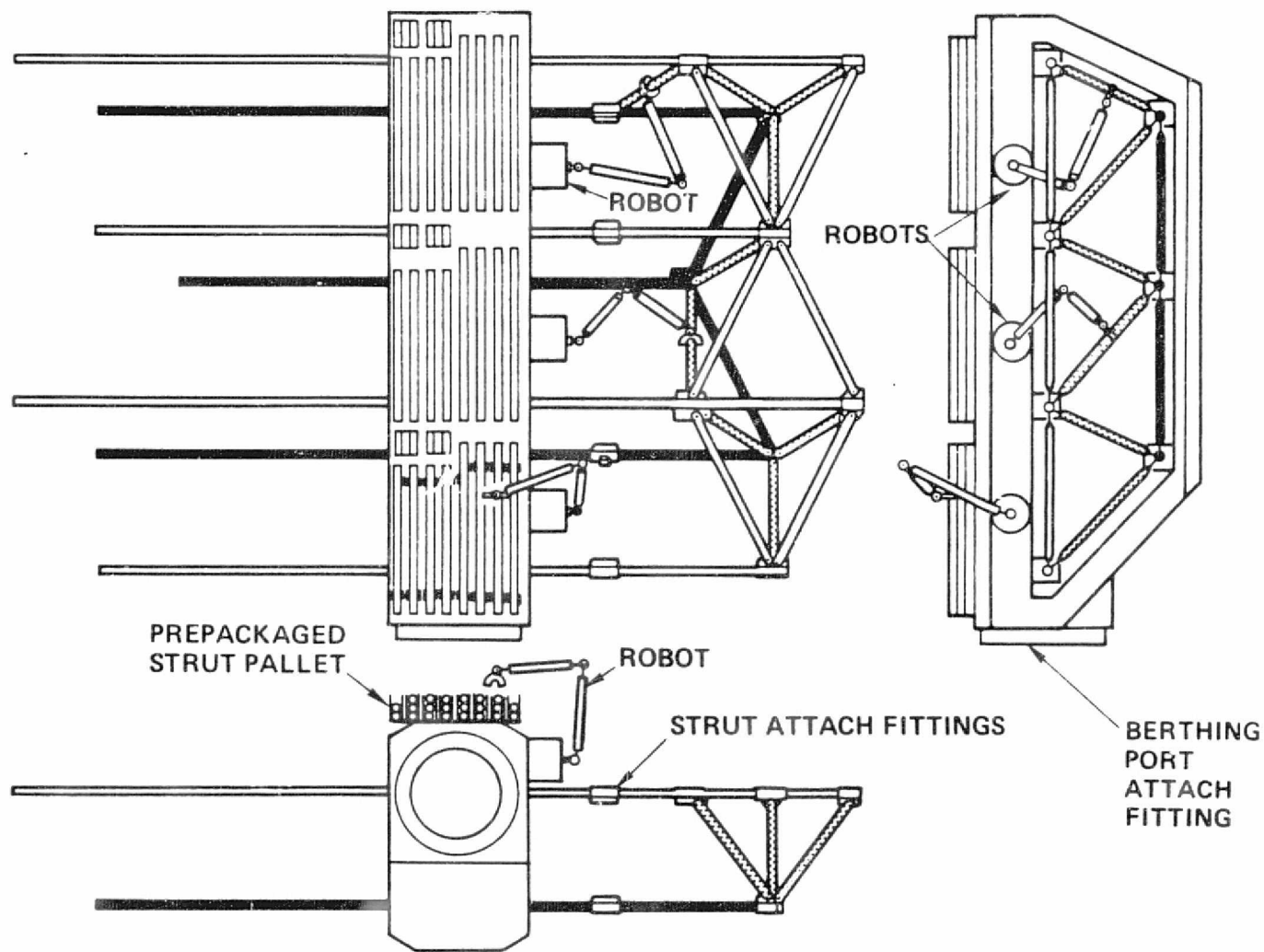


Figure 2.1.1-9. SPS TA-1 and TA-2 Antenna Assembly Fixture

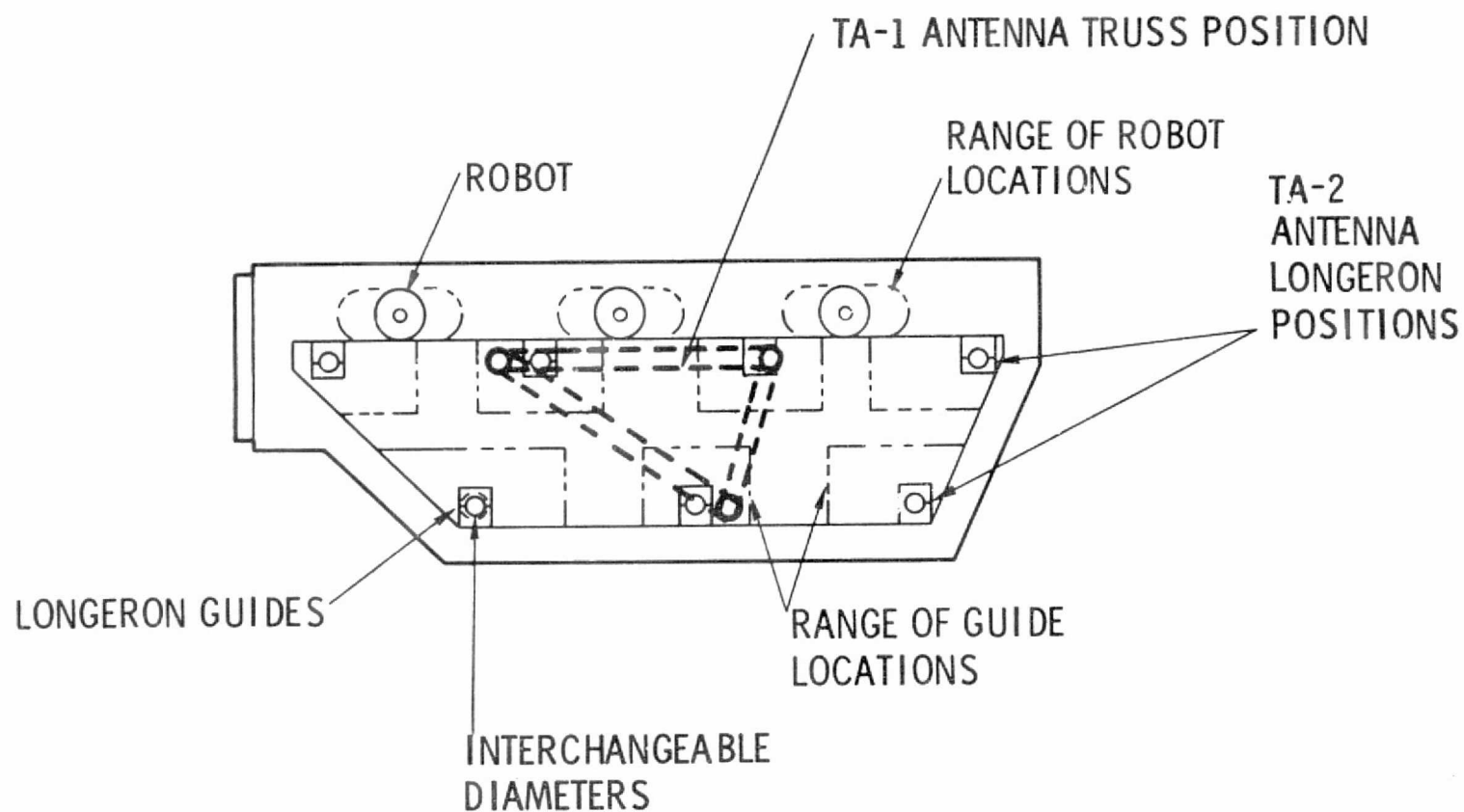


Figure 2.1.1-10. SPS TA-1 Antenna Assembly Fixture

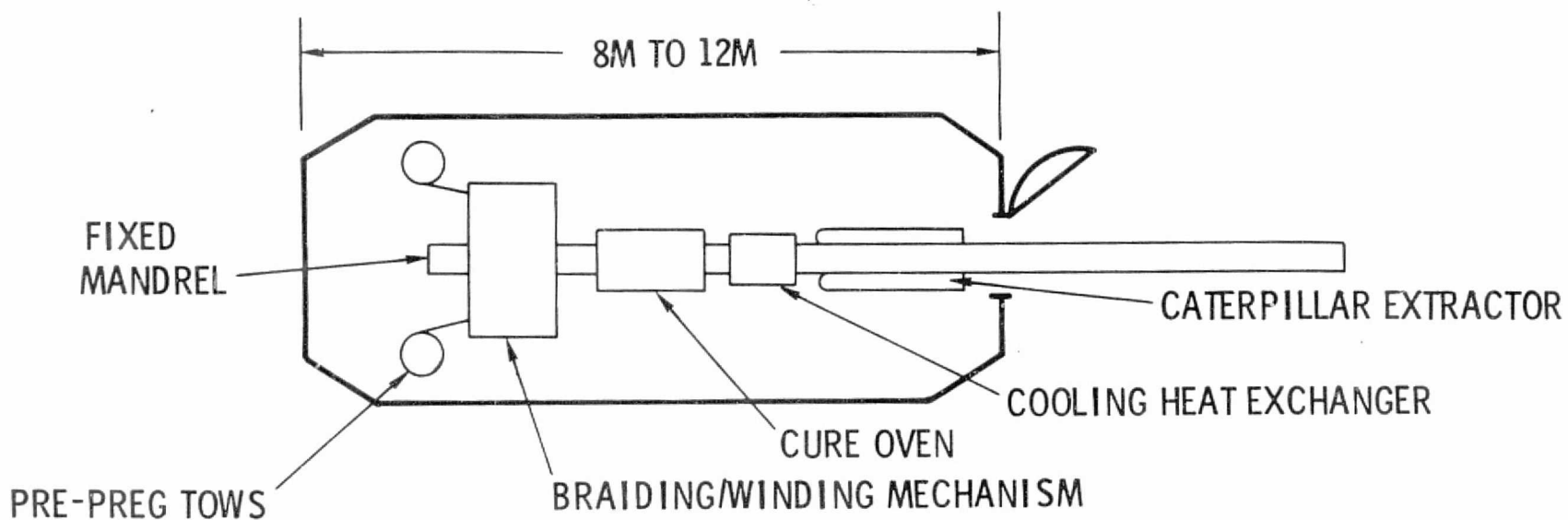
Table 2.1.1-4  
TA-1 AND TA-2 ANTENNA ASSEMBLY FIXTURE  
MASS SUMMARY

	Mass (kg)
Frame and Feed Devices	1,837
Robots (3)	2,040
Attachment Mechanisms (7)	350
Checkout and Support Provisions	250
Stowage and Material Support	224
Subtotal	4,701
Contingency (25%)	1,175
Total	5,876 kg (12,954 lbm)

#### Composite Tube Fabrication Module

This module fabricates the graphite/polyimide tubing from which the antenna structure is assembled. As illustrated in Figure 2.1.1-11, the concept is a hybrid one that combines the MDAC-developed carrier braider with features of commercially available pultrusion machines. The braider continuously lays prepregged tows on a fixed mandrel. This layup is cured as it passes through the oven, propelled by the caterpillar extractor (the cooling heat exchanger is necessary for rapid production). Thus the process is continuous. To facilitate production of long tubes, the module is evacuated and opened after initial setup is accomplished in a shirtsleeve environment. Vacuum operation is feasible because the process utilizes only prepregged tows.

The fixture is capable of making constant thickness or isogrid circular tubes from 5 to 150 cm in diameter. It is also capable of making noncircular cross section tubes and weaving complex three-dimensional shapes. Tube



#### FEATURES:

- 1 COMBINATION BRAIDING, WINDING, AND HORIZONTAL FIBER LAYUP MECHANISM SIMILAR TO MDAC DEVELOPMENT ALLOWS VERSATILITY
- 2 FIXED MANDREL AND CATERPILLAR EXTRACTOR SIMILAR TO COMMERCIAL "PULTRUSION" MACHINES ALLOWS CONTINUOUS PRODUCTION OF VERY LONG TUBES

Figure 2.1.1-11. Composite Tube Fabrication Module Concept

lengths are limited only by the ability to control the free end. The weight is estimated to be about 4660 kg which would require approximately two-thirds of the Shuttle launch capability.

#### EVA Support Station

An airlock is required which is capable of accommodating three persons. This includes a crew of two in transfer to and from EVA plus an additional person, if necessary, to assist the crew members in their preparation for or return from EVA. The required airlock volume is  $10 \text{ m}^3$ , providing for pressurization and depressurization, emergency breathing support, and denitrogenation. An adjacent  $67 \text{ m}^3$  facility is required for EVA equipment charge and recharge, cooling, equipment checkout and donning, suit and tool storage, and suit reconditioning.

#### Crane/Manipulator

The SCB must provide a crane or manipulator with two arms able to reach all extremities of the antenna assembly fixture, Figure 2.1.1-6, and capable of transferring composite longerons and struts from the tube fabrication module to the antenna assembly fixture. The minimum required reach is 20 m.

The design must provide for both joint and independent crane arm control. Seven degrees of freedom will be required to permit motion of the crane body (yaw), shoulder joint (pitch and yaw), elbow (pitch), and wrist (pitch, yaw, and roll).

#### Mobility Devices

Devices may be required to transfer equipment and crewmen beyond the reach of the crane/manipulator for purposes of assembly, checkout, and/or servicing.

### Power

The power required from the SCB during construction will average 6 kWe with a peak of approximately 10 kWe. During test, average and peak power from the SCB will be approximately 5 kWe and 80 kWe (20 kV), respectively.

### Control Center

Equipment for remotely monitoring and controlling the automatic construction processes must be centralized in an SCB control center. The equipment will include closed-circuit TV monitors for each fabrication and assembly function. During test, the control center must be equipped to monitor, display, and evaluate TA-1 functional parameters (e.g., antenna geometric pointing and electronic steering angles).

A command transmitter and associated controls will be required to command TA-1L and BMS operations. Display capability (TBD) will also be needed (not continuous; stored information used). Display data will include, for example, BMS position and rate information. The SCB caution and warning system will provide safety support for the TA-1 missions. For instance, a warning would be signalled if the BMS got too close to the antenna and SCB.

The BMS will be tracked using a range-only microwave radar and two cameras — boresight and tracking. The radar will be used to determine BMS range to an accuracy of  $\pm 150$  m. The boresight camera measures the angle from the antenna geometric axis to within 1 sec. It is a long-focal-length, time-lapse, 20-cm optics camera mounted on the TA-1 antenna. Zoom lens video provides control center display. Computer processing of video information measures angles to within 1 mrad. Film development and reader equipment will be required aboard the SCB to support measurement of TA-1 angular displacements. The tracking camera provides video during RFI testing for measuring large BMS angular displacements from the antenna axis to an accuracy of  $\pm 8$  mrad.

### Data and Communcations

TA-1 requires the following capabilities:

<u>Activity and Item</u>	<u>Data Rate or Bandwidth</u>
Construction	TBD
Data link	
(Other, TBD)	
Test	TBD
Command	
Instrumentation	
Beam Mapping Satellites	
(Other, TBD)	

### Electromagnetic Interference Control

The SCB must be designed so that its operation cannot be interfered with by the test article operation.

### Berthing

Provisions must be made for berthing:

- A. TA-1 during construction and test.
- B. Composite tube fabrication module during construction.
- C. TA-1 antenna assembly fixture during and after construction.
- D. Logistic modules (simultaneous berthing required prior to construction start):
  1. Antenna assembly fixture and TA-1G satellite subsystem module and structure standoff (~1 module)
  2. Composite tube fabrication module (~2/3 module)

### Orientation

During assembly it may be necessary to point the longitudinal axis of the antenna to the sun in order to minimize thermal distortions. During test operations, the plane of the antenna must be oriented normal to the velocity vector. The duty cycle for the test orientation is an average of 2 orbits per day for approximately 8 months.



### Environmental Control

Temperature, humidity, and cleanliness requirements for the control center are those for SCB shirtsleeve activity.

### Acceleration

Lightweight antenna support structure is used to minimize weight and cost. Accelerations must be maintained below 2 g to avoid overstressing the structure. Accelerations must be less than  $\sim 0.05$  g with the TA-1 solar array deployed for checkout due to the array's fragility in that configuration.

### Contamination

Effluents, outgasing, and products of propulsion must not impinge on or form clouds (TBD particles/cm<sup>3</sup>) about the amplitrans in order to preclude arcing. Also, impingement on the deployed TA-1 solar array is to be avoided.

### Safety

Field strength measuring devices of TBD sensitivity will be strategically located aboard the SCB to monitor and measure the microwave doses the crew is being exposed to. This will assure that dose limits are not exceeded.

### Workshop

TA-1 construction and test will require the use of a pressurized general purpose workshop for maintenance and repair of equipment (20 m<sup>3</sup>).

### Logistics

A total of approximately 1-2/3 Shuttle flights to orbit are required in accordance with the breakdown under "berthing" above. The TA-1 will not employ scheduled maintenance. Periodic unscheduled servicing (including modular replacement of failed elements) will be required during the operating life of TA-1.

### Personnel

The SCB will provide personnel as follows:

<u>Item</u>	<u>Crew Size</u>	<u>No. of Shifts</u>
Assembly and checkout of construction equipment	3	20
Construction	3	60
Test/evaluation	1	970

### Warehousing

Approximately 50 m<sup>3</sup> of external storage space must be maintained aboard the SCB for temporary storage of TA-1 parts unloaded from the Shuttle during construction. This volume is in addition to berthing and storage requirements for TA-1 tooling and fixtures.

### Scrap Control

A method will be required for controlling, storing, and disposing of scrap materials resulting from fabrication and assembly equipment checkout and TA-1 construction.

## 2.1.2 SPS Test Article 1G

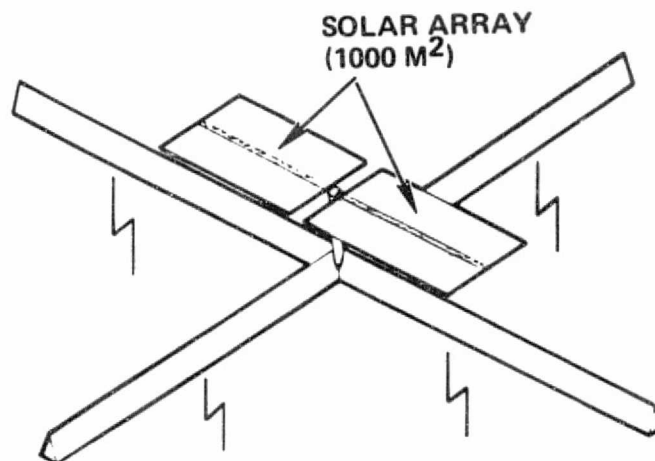
### 2.1.2.1 Mission Overview

The functions, basic configuration, and characteristics of SPS Test Article 1 in GEO (TA-1G) are summarized in Figure 2.1.2-1. TA-1G will operate in a ground-controlled, unmanned mode. The SCB role for TA-1L/TA-1G will be complete with LEO checkout and launch to GEO of the TA-1G configuration. TA-1G will be transported to GEO under ground control by an Interim Upper Stage (IUS) that is transported to LEO by a single Shuttle flight. Operation in GEO may then be as long as 12 years in order to span a complete solar cycle. TA-1G will be stationed at the 120 deg W longitude GEO stable libration point at an inclination of 7.3 deg in order to provide an orbit which is fixed in space and minimizes the satellite propellant requirements.

### 2.1.2.2 Mission Hardware Description

TA-1G will use the same hardware as TA-1L, except the solar arrays, retracted during transport, will be extended at GEO. The antenna is made up of a pair of tapered linear arrays in a cross configuration. The arms of the cross are 123 x 125.6 m long. Details of the antenna were presented in Section 2.1.1.2. The solar arrays are adapted from the SCB design and are rated at 100 kWe beginning-of-life.

The primary sizing criteria for TA-1 (L and G) are related to the need for large-aperture (narrow-beam), two-dimensional (2D) phase control tests from GEO through a heated ionosphere region. The cross configuration, as contrasted to a linear configuration, is driven by the need for 2D testing. The ionosphere will be heated by a high-frequency (10 MHz), high-power beam from the ground. The 123-m aperture will provide a beamwidth that matches the heated ionosphere region (74 km diameter at 380 km altitude). The relatively large 123-m aperture in a tapered linear array configuration will provide good phase control testing and will minimize the ground beam mapping problem by providing a smaller ground spot size.



#### REQUIRED GEO FUNCTIONS

##### EVALUATE SPACE CONSTRUCTION OF LARGE STRUCTURES

- MICROWAVE ANTENNA
- STRUCTURAL INTERFACES

##### EVALUATE LARGE-SCALE MICROWAVE TRANSMISSION AND PHASE CONTROL

- IONOSPHERIC DEGRADATION OF PHASE CONTROL SYSTEM
- THERMOSTRUCTURAL EFFECTS ON PHASE CONTROL SYSTEM

##### EVALUATE RFI EFFECTS OF ENERGY TRANSFER

- DIRECT TRANSMISSION FROM AMPLITRONS
- SWITCHING SOURCES
- VOLTAGE-LEVEL REGULATION
- IONOSPHERE-INDUCED

##### EVALUATE HIGH VOLTAGE AND SPACE PLASMA EFFECTS

- ARCING AND LEAKAGE
- SPACECRAFT CHARGE PHENOMENA

#### CHARACTERISTICS FOR GEO OPERATIONS

MODIFIED SCB SOLAR ARRAY (100 KWE BEGINNING-OF-LIFE)

AMPLITRON OUTPUT – 57 KW<sub>RF</sub>

ANTENNA DIMENSIONS – 123 X 125.6 M

WEIGHT TO GEO – 5926 KG

TRANSPORTED TO GEO BY IUS

Figure 2.1.2-1. SPS Test Article 1, GEO

### 2.1.2.3 Activity and Test Descriptions

#### Technical Objectives

The technical objectives of TA-1 are listed in Table 2.1-3 of Section 2.1 and briefly summarized in Figure 2.1.2-1.

#### Activity Description

The TA-1L activities are assumed completed and the TA-1G activities started at the time of launch to GEO on the IUS. At this time, mission control is turned over to the ground. Hence, TA-1G imposes no requirements for SCB support, except for TA-1G's strong influence on TA-1L and its associated activities, which were described in Section 2.1.1.

#### Test Requirements

The test requirements relate to long-term operation in the GEO environment and phase-control tests, including tests of the heated and unheated ionosphere as discussed in Section 2.1.2.2. The impact of these unmanned, ground-controlled tests on the SCB is through TA-1 sizing and configuration. These effects have been accounted for in the TA-1L discussions of Section 2.1.1.

#### Test Description

The GEO tests consist basically of repeated beam mapping (at different times of the day and year for 12 years) while under pilot beam control both with and without ionosphere heating from the ground. Typical candidate ground sites are Arecibo, Puerto Rico and White Sands, New Mexico. Again, the effects of the unmanned TA-1G tests on the SCB have been accounted for, as noted above.

### 2.1.2.4 Space Construction Base Requirements

The SCB requirements stemming from TA-1G operations have been covered in the TA-1L discussion of Section 2.1.1.

### 2.1.3 SPS Test Article 2

#### 2.1.3.1 Mission Overview

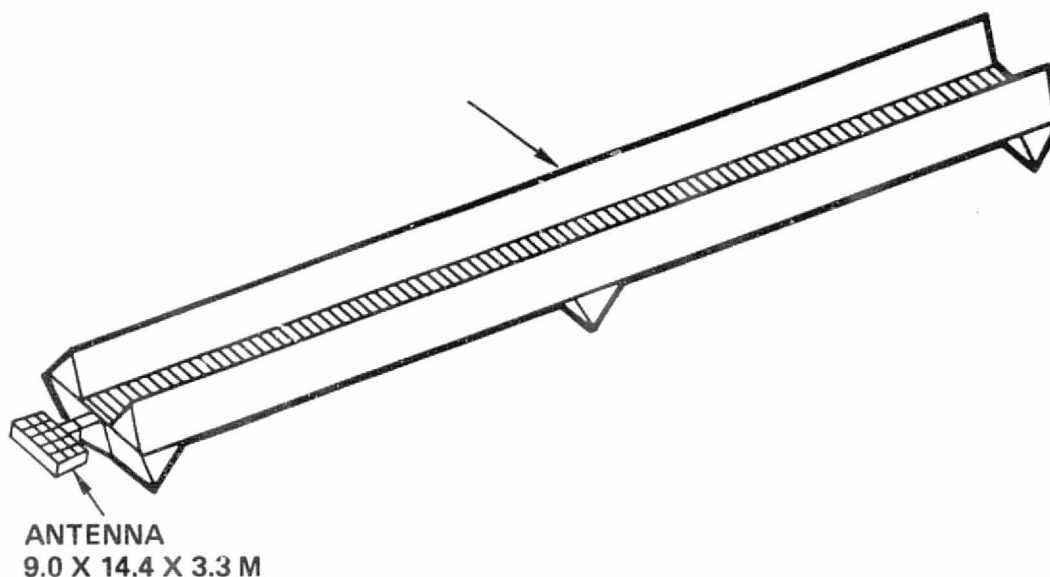
SPS Test Article 2 (TA-2) embodies the third phase of the four-phase SPS development program described in Section 2.1. TA-2 must provide by 1987 sufficient data to help establish the basis for making SPS development decisions. Consequently, it must provide both an early demonstration of concept feasibility and engineering data for the SPS prototype design upon which future design and cost estimates can be firmly based. This will be accomplished through an integrated system feasibility demonstration of fabrication, assembly, checkout, operation, and system performance on a prototype scale. TA-2 will also provide data on space alignment, failure detection, and maintenance of large solar collectors and microwave antennas.

TA-2 will operate at a nominal altitude of approximately 400 km (216 nmi) and an inclination of 28.5 deg. This is a compromise altitude considering high drag at low altitudes, and radiation and reduced Shuttle capability at high altitudes. TA-2 is constructed and operated attached to the SCB.

#### 2.1.3.2 Mission Hardware Description

The functions, configuration, and characteristics of TA-2 are summarized in Figure 2.1.3-1. The 30-m dimension of the solar collector is the dimension at the extreme width; the active portion of the solar collector is 20 m wide. The 17-m depth is from the top of the reflector to the bottom of the 10-m beam cross braces. The reflector structure and the cross braces are of the same 10-m beam design that would serve as caps for the 640-m beam in the JSC SPS prototype concept.

A detailed view of the TA-2 is presented in Figure 2.1.3-2. A mass summary is presented in Table 2.1.3-1.



#### FUNCTIONAL REQUIREMENTS

EVALUATE SPACE CONSTRUCTION OF LARGE STRUCTURES

- SOLAR COLLECTOR
- MICROWAVE ANTENNA
- STRUCTURAL INTERFACES

EVALUATE LARGE-SCALE ENERGY COLLECTION AND DISTRIBUTION

- 20,000 V
- SWITCHING

EVALUATE LARGE-SCALE MICROWAVE TRANSMISSION AND PHASE CONTROL

- THERMOSTRUCTURAL EFFECTS ON PHASE CONTROL SYSTEM

EVALUATE RFI EFFECTS

- DIRECT TRANSMISSION FROM AMPLITRONS
- SWITCHING AND ROTARY JOINT SOURCES
- VOLTAGE-LEVEL REGULATION

EVALUATE HIGH VOLTAGE AND SPACE PLASMA INTERACTION

- ARCING AND LEAKAGE

END-TO-END FUNCTIONAL VERIFICATION

- THERMAL/STRUCTURAL INTERACTION
- PHASE CONTROL SYSTEM
- POWER TRANSFER/ROTARY JOINT CURRENT DENSITY

#### CHARACTERISTICS FOR GEO OPERATIONS

ANTENNA POWER – 479 KW<sub>RF</sub>

COLLECTOR POWER – 715 KWE

CENTER SUBARRAY – MAX POWER DENSITY – 20 KW/M<sup>2</sup>  
~ 3 X 3M SUBARRAYS

PROTOTYPICAL 10-M BEAMS

WEIGHT – 22,330 KG

Figure 2.1.3-1. SPS Test Article 2

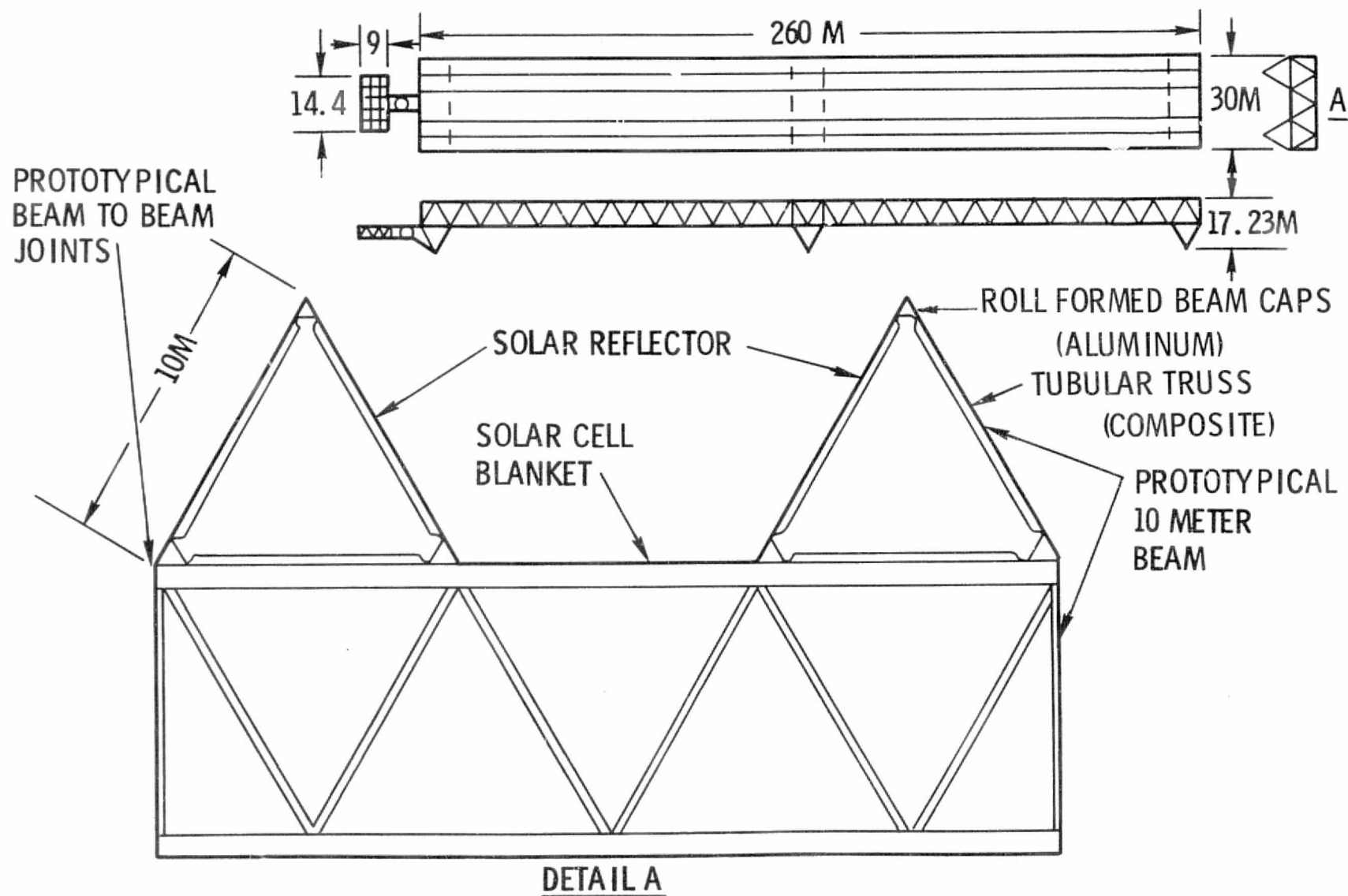


Figure 2.1.3-2. SPS Test Article 2 Layout



Table 2.1.3-1  
TA-2 MASS SUMMARY

		Mass (kg)
Solar Collector	14,316	
Structure		12,027
Solar Cell Blanket		1,790
Reflectors		499
Microwave Antenna	2,098	
Amplitrans		174
Waveguide Panels		643
Phase Control Electronics		680
Panel Leveling Device		101
Thermal Protection (Electronics)		150
Structures		350
Rotary Joint and Supports	1,150	
Supporting Subsystems	300	
Subtotal	17,864	
Contingency (25%)	4,466	
Total	22,330 kg (49,240 lbm)	

TA-2 sizing is dictated by RF power requirements which, in turn, dictate solar collector size. The requirements of Table 2.1-1 (Section 2.1) call for the use of maximum power density ( $20 \text{ kW/m}^2$ ) to evaluate thermostructural and RFI problems. Since the smallest subarray that will provide useful data is believed to be approximately  $3 \times 3 \text{ m}$ , the power transmitted by this single subarray will be approximately  $180 \text{ kW}_{\text{RF}}$ ; this subarray size is Shuttle-compatible. It is also believed that a minimum of 15 subarrays is necessary to adequately demonstrate phase control of a clustered array and to test for associated thermostructural and RFI effects. Since the additional 14 subarrays may be run at near-minimum power density (approximately  $2.4 \text{ kW/m}^2$ ), total antenna RF power is approximately  $480 \text{ kW}_{\text{RF}}$  for the final amplitrans configuration (down from the initial estimate of  $513 \text{ kW}_{\text{RF}}$ ). Considering the achievable conversion, distribution, and conditioning efficiencies, the associated solar collector is sized at  $5200 \text{ m}^2$  active area for a net output of 715 kWe.

### Solar Collector

All TA-2 mission hardware is designed to support development of the selected SPS concept. While evolution of this selection process will not be complete for some years to come, a prototype design concept model has been selected for the solar collector from JSC in-house studies for the purpose of defining detailed test article requirements (see Figure 2.1-1). This JSC prototype design model can be constructed of a single generic structural element — a 10-m triangular cross section truss beam. Thus the development and demonstration of the 10-m beam is a primary objective of the TA-2 design and test effort.

The TA-2 concept employs prototypical 10-m beams to form a 260-m-long solar collector. Figure 2.1.3-3 further illustrates the use of prototypical 10-m beams to construct the solar collector. While the reflector and solar cell blanket are necessarily restricted to 10 m in width, materials and particularly the tooling for attaching these components during assembly can be prototypical. Since TA-2 employs 10-m beams as both longerons and cross members, prototypical beam-to-beam attachments will also be demonstrated.

### Microwave Antenna

An overview of the TA-2 antenna is presented in Figure 2.1.3-4. The antenna consists of panels made up of ground-fabricated waveguide and amplatron sections attached to a support structure which is assembled on orbit. The phase control electronics are located at the bottom of the structure and provided with a thermal reflector/shield to minimize heating problems for this thermally sensitive equipment.

An overview of the microwave elements of the TA-2 antenna is shown in the small sketch in the upper-right-hand corner of Figure 2.1.3-5. Layout details of the maximum power density center subarray are shown in the upper portion of the blown-up subarray; in this case, the amplatron thermal radiators are almost touching. Each amplatron corporate feeds five waveguides which are each 0.4786 m long. There are 36 amplatrons in this subarray, each feeding a 0.4786- x 0.4976-m element.

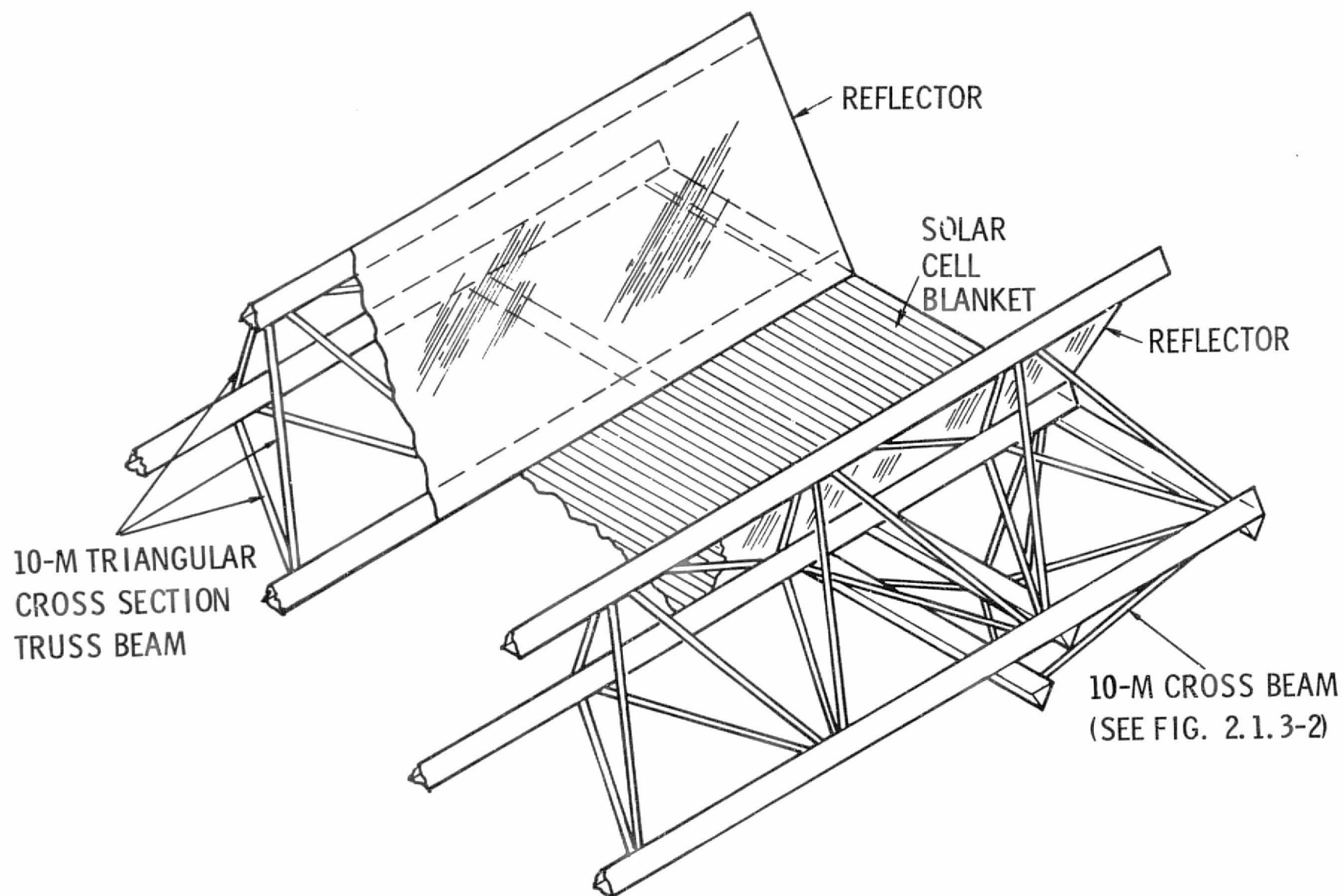


Figure 2.1.3-3. SPS TA-2 Solar Collector

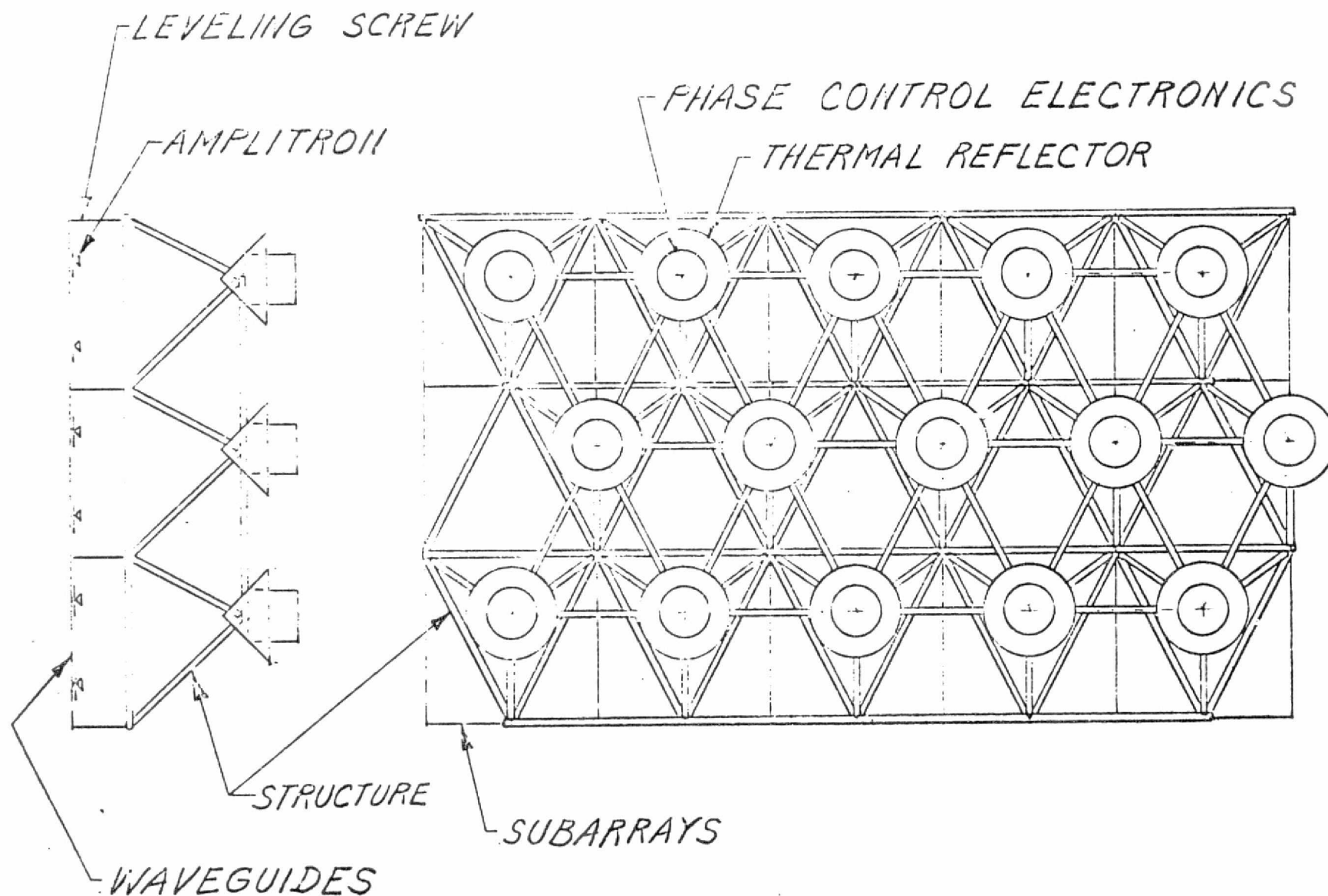


Figure 2.1.3-4. SPS TA-2 Antenna

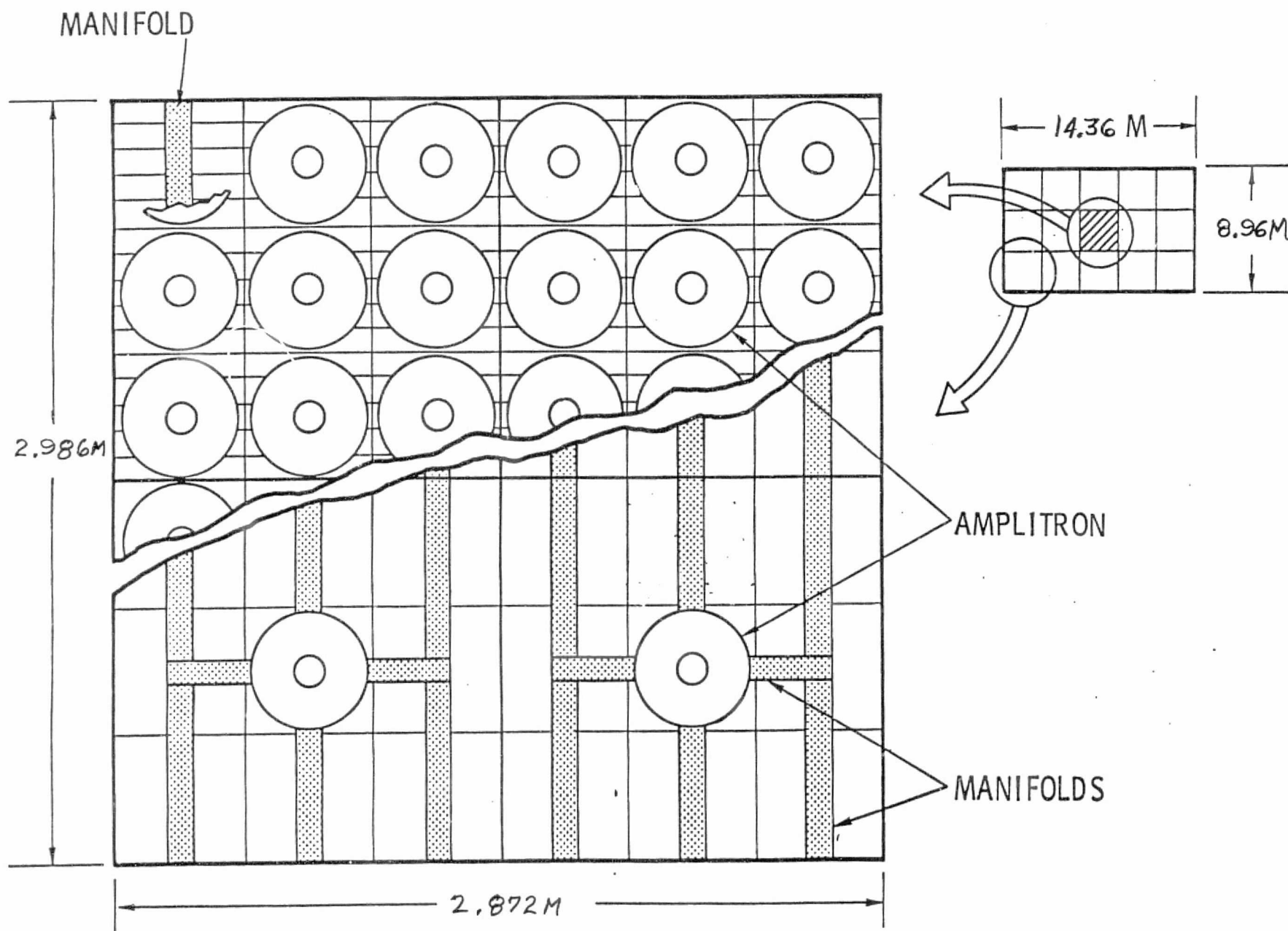


Figure 2.1.3-5. SPS TA-2 Cluster Antenna

The lower portion of the blow-up shows the low power density subarray layout. Each subarray has four amplitrans with a multiple corporate feed down to the same element (five waveguides wide and 0.478 m long; not pictured at the waveguide level).

The TA-2 antenna structure (Figure 2.1.3-6) is sized to support 15 (3 x 5) 3-m-square subarrays; it is assembled from 15-cm-diameter composite (graphite-polyimide) tubes.

The TA-2 antenna support structure is patterned after the SPS prototype model, a two-layer structure with a secondary truss structure sized to support the square antenna subarrays at three truss intersection points (Figure 2.1.3-7). Consequently, the planar truss secondary structure is another primary TA-2 development objective.

#### Rotary Joint

The rotary joint utilizes the JSC spherical concept and is scaled to employ prototypical power densities. It is capable of continuous rotation about one axis and  $\pm 10$  deg about another. The servo control system is capable of controlling the antenna to within mrad of any desired orientation with respect to the construction base velocity vector. Since the solar collector dynamic limit cycle oscillations are expected to exceed this figure, the antenna control system must be referenced to attitude instrumentation on the antenna. Maximum required antenna rotation rates are 10 deg per minute. The electrical power system utilizes the solar collector source with self-contained conditioning and battery storage. This subsystem is fabricated and assembled on the ground.

#### Supporting Subsystems

The TA-2 supporting subsystems are relatively simple since they are attached to the SCB. Basic functions include command and control and instrumentation. These functions are performed by an instrumentation and signal-conditioning subsystem coupled to the SCB by a data bus. These subsystems are supported by power from the SCB to ensure reliable operation and continuity during eclipse periods.

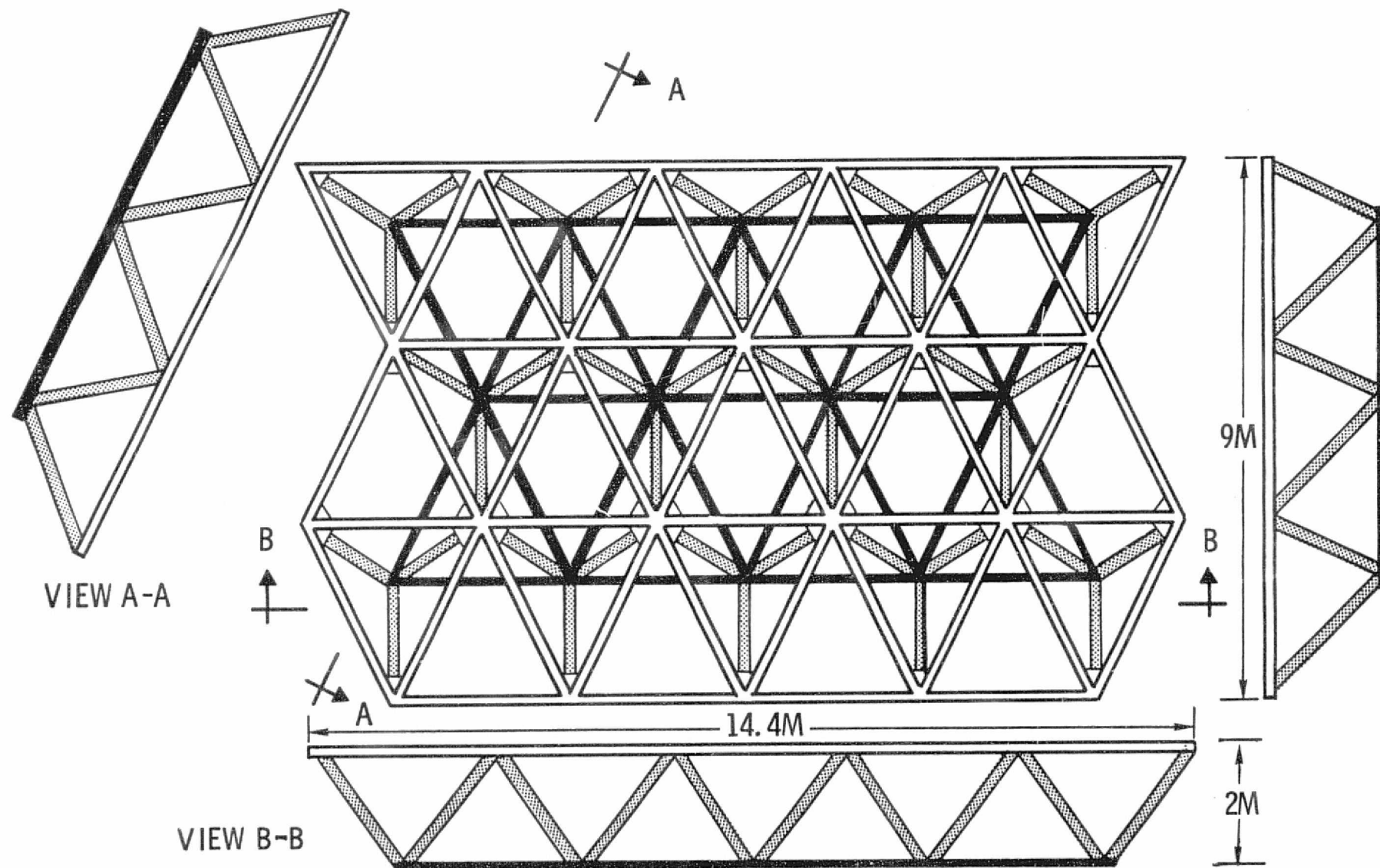


Figure 2.1.3-6. SPS TA-2 Antenna Structure

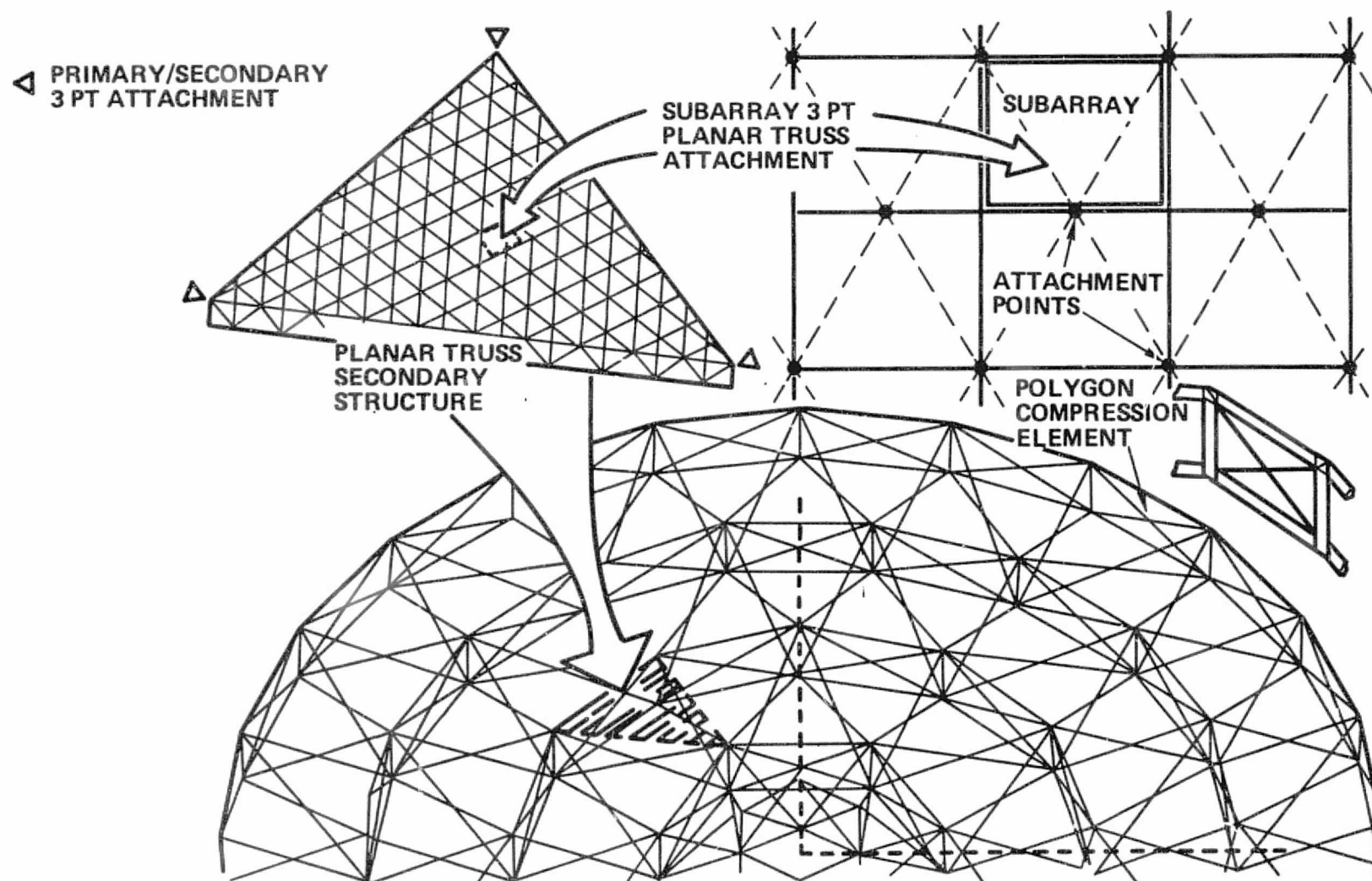


Figure 2.1.3-7. Prototype Model Antenna-JSC Structure Design Concept



### Beam Mapping Satellite

Two beam mapping satellites (BMS-QC and BMS-C) will be used to test TA-2. They are shown, with their functions, in Figure 2.1.3-8. (These same satellites are used to test TA-1.)

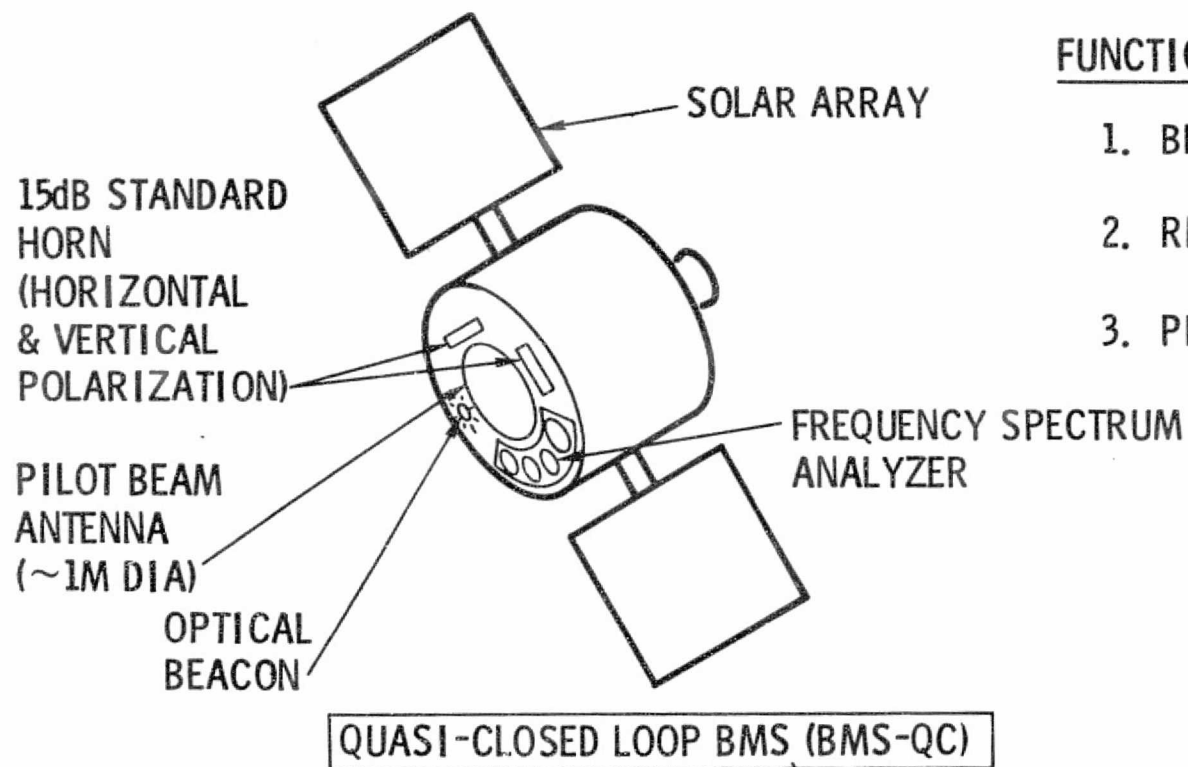
The BMS's are unmanned vehicles used for mapping TA-2 microwave beam patterns and frequency content. Their functions are to (1) map microwave radiation patterns to an angle of  $\pm 10$  deg about the TA-2 antenna axis, (2) evaluate RFI to an angle approaching  $\pm 180$  deg from the antenna axis, and (3) provide the phase control pilot beam when required.

The BMS will operate in the same orbit as the SCB at 3.4 km, the near edge of the far field where the beam is properly formed. Mapping is accomplished by electronically sweeping a beam past the satellite. Instrumentation consists of field-strength measuring devices and a frequency spectrum analyzer. The BMS also contains (1) a microwave pulse transponder for range (to construction base) measurement, (2) an optical beacon (high intensity strobe light) for accurate measurement of the satellite's angular position from the TA-2 antenna geometric centerline, and (3) a telemetry system.

Spacecraft systems include (1) an attitude control system to allow pointing of body-mounted sensors and beacons, (2) a propulsion system to allow station-keeping and maneuvering, and (3) a command and control system that allows the beam mapping satellite to be controlled from the SCB.

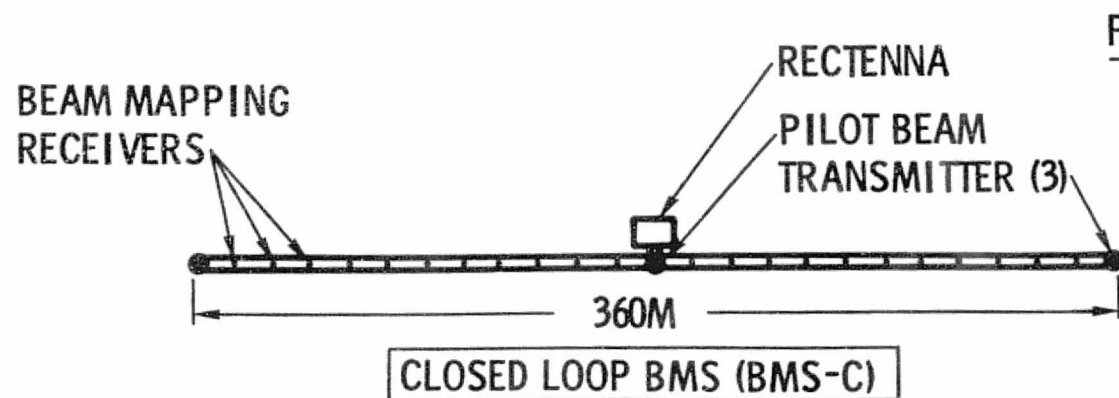
BMS-QC (quasi-closed loop) provides the pilot pulse via the pilot beam antenna ( $\sim 1$  m in diameter). It maps the TA-2 beams using two 15-db standard horn antennas, one for horizontal and one for vertical polarization. The optical beacon serves as a target for the TA-2 optics system to provide array normal line-of-sight data with respect to the BMS line of sight. The frequency spectrum analyzer is depicted by a series of antennas for various frequencies to evaluate out-of-band RFI.

BMS-C (closed loop) consists of a rectenna and a 360-m-long structure with three pilot beam transmitters (one in the middle and one at either end) and a



### FUNCTIONS

1. BEAM MAPPING MEASUREMENTS
2. RFI MAPPING MEASUREMENTS
3. PROVIDE PILOT PULSE SOURCE



### FUNCTIONS

1. CLOSED LOOP BEAM MAPPING
2. TA-2 POWER TRANSFER

Figure 2.1.3-8. Beam Mapping Satellites

series of beam mapping (field strength measuring) receivers. The BMS-C can map the beam at the same time one of the pilot beams is operated; therefore, it can simulate the SPS operation more closely than the BMS-QC can. (The use of BMS-QC requires the recording of pilot beam signals for slightly delayed replay.)

At 3.4 km, the 360-m length of the BMS-C permits TA-2 beam mapping of (1) one-half the main lobe and approximately 12 lobes on one side when one of the end pilot beam transmitters is operating, and (2) the main lobe and approximately six lobes on each side, using the center pilot beam transmitter. A three-dimensional beam map can be obtained by rotating the BMS-C about the test article-to-satellite line of sight to various angular positions and repeating the test. The rectenna used for power transfer demonstration is approximately 15 x 20 m in size.

The BMS-QC is expected to weigh less than 1000 kg and require on the order of a few hundred watts of peak electrical power provided by an oriented solar array and battery system. The overall satellite is approximately 2 m in diameter and 2 m long. An existing unmanned satellite can probably be adapted to be a suitable carrier vehicle. In particular, communications satellites generally have both the propulsion and command and control capabilities required by BMS-QC. The propulsion capability is 500 m/sec. This vehicle probably will be small enough to be included as cargo on a regular Orbiter logistics flight, and since the BMS always operates in close vicinity to the SCB, it could be serviced on orbit by the Shuttle as part of an SCB mission.

Another leading candidate for the BMS-QC carrier vehicle is the Multimission Modular Spacecraft (MMS) currently in development by NASA. The MMS has a distinct advantage in that it is designed to be retrieved, refurbished, and relaunched by the Space Shuttle.

The BMS-QC is similar to the satellite required for the Earth Services antennas. A common carrier vehicle with special payload instrumentation for each of the applications is tentatively planned. Because BMS-QC and BMS-C are Shuttle launched and serviced, they place no major technical requirements on the SCB.

### 2.1.3.3 Activity and Test Descriptions

Test article construction, with its related activities and operations, and test article operations are described in this section. The technical objectives of TA-2 are identified in Table 2.1-3, Section 2.1. These objectives are also summarized in Figure 2.1.3-1.

#### Activity Description

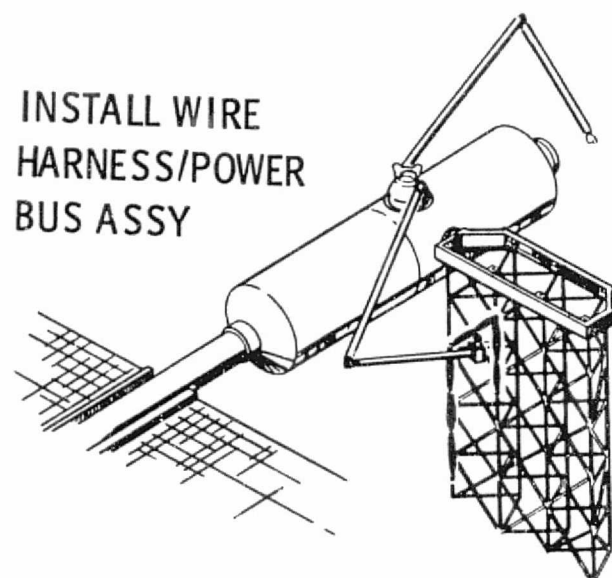
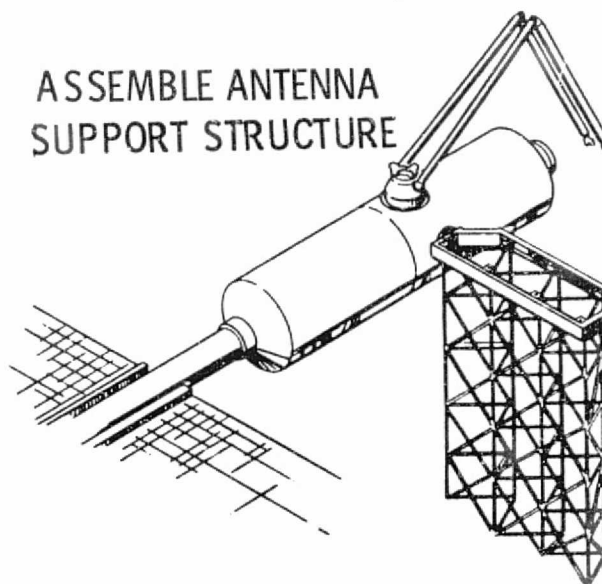
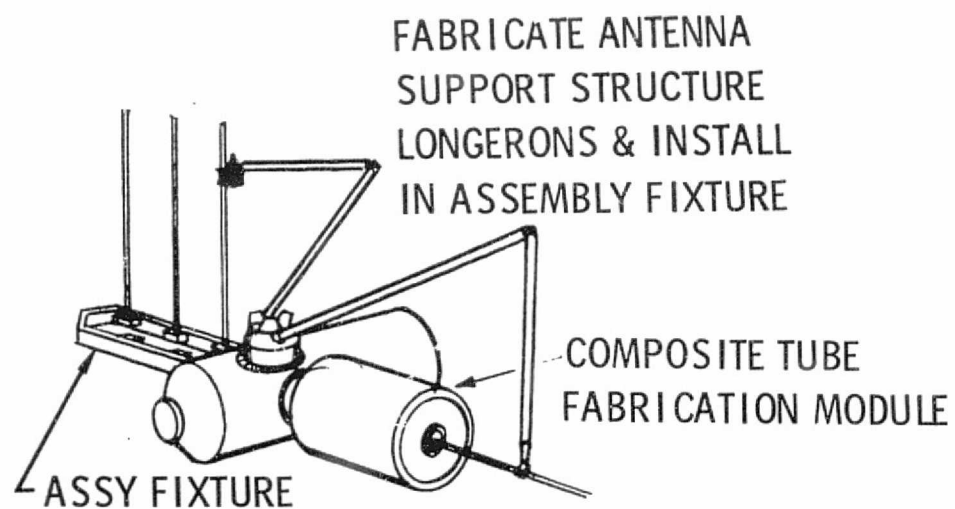
Figure 2.1.3-9 summarizes the construction activities for the TA-2 antenna. The support structure is assembled from graphite polyimide tubes which are fabricated on orbit by a composite tube fabrication module (described in Section 2.1.3.4). The tubular longerons are inserted in an assembly fixture containing automatic feeds. Support struts are put in place and attached using standard industrial robots attached to the fixture.

The wire harness and power bus assembly and the antenna panels are attached by EVA. The last step (not shown) consists of installing an attach fitting and gimbal (a part of the rotary joint) for subsequent joining of the antenna to the TA-2 solar collector.

The solar collector construction activities are summarized in Figure 2.1.3-10. The construction of TA-2 is predicated on automatic beam forming. A construction fixture frame is brought up to the SCB, assembled (by EVA and crane), and aligned. Six automatic beam cap forming modules are then brought up and one module is installed on the frame at each triangular beam apex (see Figure 2.1.3-10, Sketch 1). Industrial robots are then installed in the proper locations to position ground-fabricated support struts during assembly of the 10-m beams. Four and 1/3 Shuttle launches will be required to deliver the solar collector construction fixture, the tube fabrication module, the antenna assembly fixture, and construction supplies.

The beam cap forming machines roll-form the caps which are extruded at a uniform synchronized rate. At the appropriate time, a strut is loosely attached by spring clips at the appropriate point by the industrial robot, and a spot-welding mechanism energized to fix it in place. Three 30-m-long beams are constructed in this manner, and then temporarily stored.

Construction of the solar collector support structure is then initiated. End caps are installed by EVA and a little more than 10 m of structure extruded.



ATTACH ANTENNA PANELS

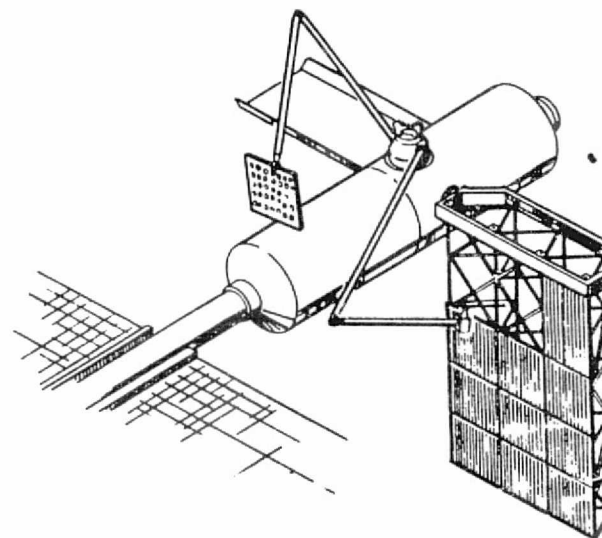
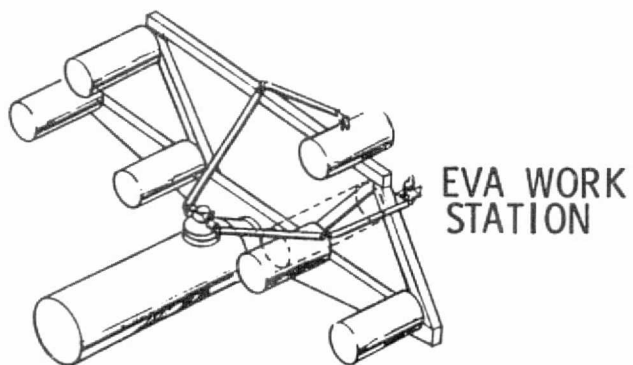
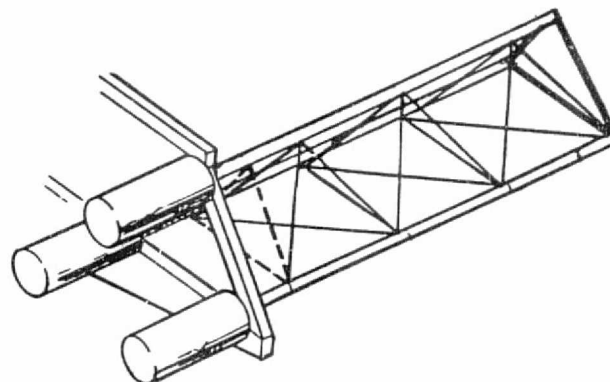


Figure 2.1.3-9. SPS TA-2 Antenna Fabrication and Assembly Sequence

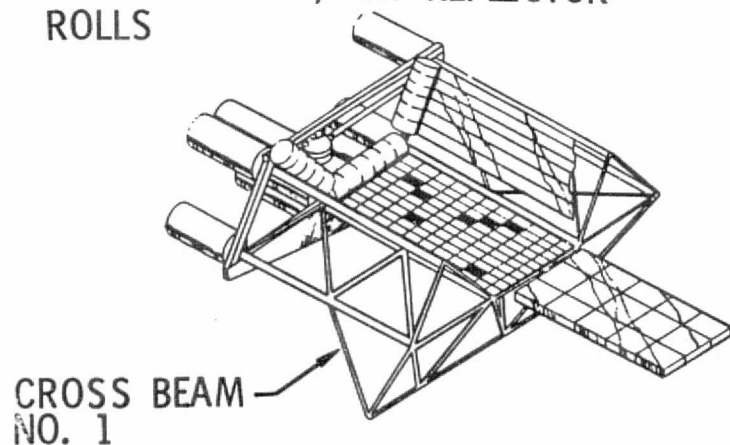
① ASSEMBLE SOLAR COLLECTOR CONSTRUCTION FIXTURE



② CONSTRUCT THREE 30M CROSS BEAMS



③ CONSTRUCT INITIAL SECTION OF SOLAR COLLECTOR FRAMEWORK  
ATTACH ANTENNA, CROSS BEAM NO. 1, SOLAR BLANKET, AND REFLECTOR ROLLS



④ COMPLETE CONSTRUCTION OF TA-2

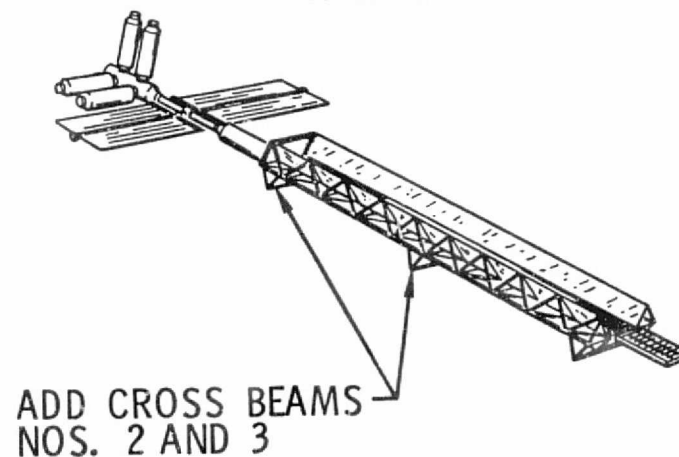


Figure 2.1.3-10. SPS TA-2 Solar Collector Construction

A 30-m cross beam is put in place by the crane and attached by EVA. The antenna is brought around and attached at the end of the solar collector structure. Solar cell blankets and reflector rolls are installed on the fixture, then unrolled and attached to the support structure by EVA and crane. A 125-m length of collector is then constructed, and the second cross beam installed. The full 260-m is then constructed and the last cross beam installed.

Operational analysis of TA-2 construction resulted in the definition of approximately 40 major steps (summarized in Figure 2.1.3-11) involved in construction. Each step was examined, and time in terms of work shifts was determined. It should be noted that installation, checkout, and certification of the tooling were the most time-consuming tasks. Another time-consuming job will be the initial construction of proof parts and adjustment of the robot operations. The beams are then constructed relatively rapidly since the operation is automated. Activities involving EVA — primarily the installation of antenna panels — are also time-consuming. The resultant assembly time is 160 shifts averaging 3 men per shift.

#### Test Requirements

The TA-2 test requirements stem from the SPS development requirements shown earlier in Tables 2.1-1 and 2.1-3. The development requirements specifically addressed by TA-2 are indicated in Table 2.1-3.

The detailed requirements for TA-2 are based primarily on two considerations:

1. Space construction processes must be developed and the resulting lightweight structures operated in space since adequate environmental simulation is impractical on the earth's surface.
2. Large antennas employing prototype RF generators must be tested in space because it is impractical to provide the large vacuum-containing, distortion-free radome that a ground test would require.

In addition, TA-2 is to utilize and demonstrate prototype components, processes, voltages, power densities, and other concepts to the maximum extent possible. These considerations indicate that the requirements for end-to-end functional verification and evaluation of space construction can best be met by constructing a reasonably large-scale test article consisting

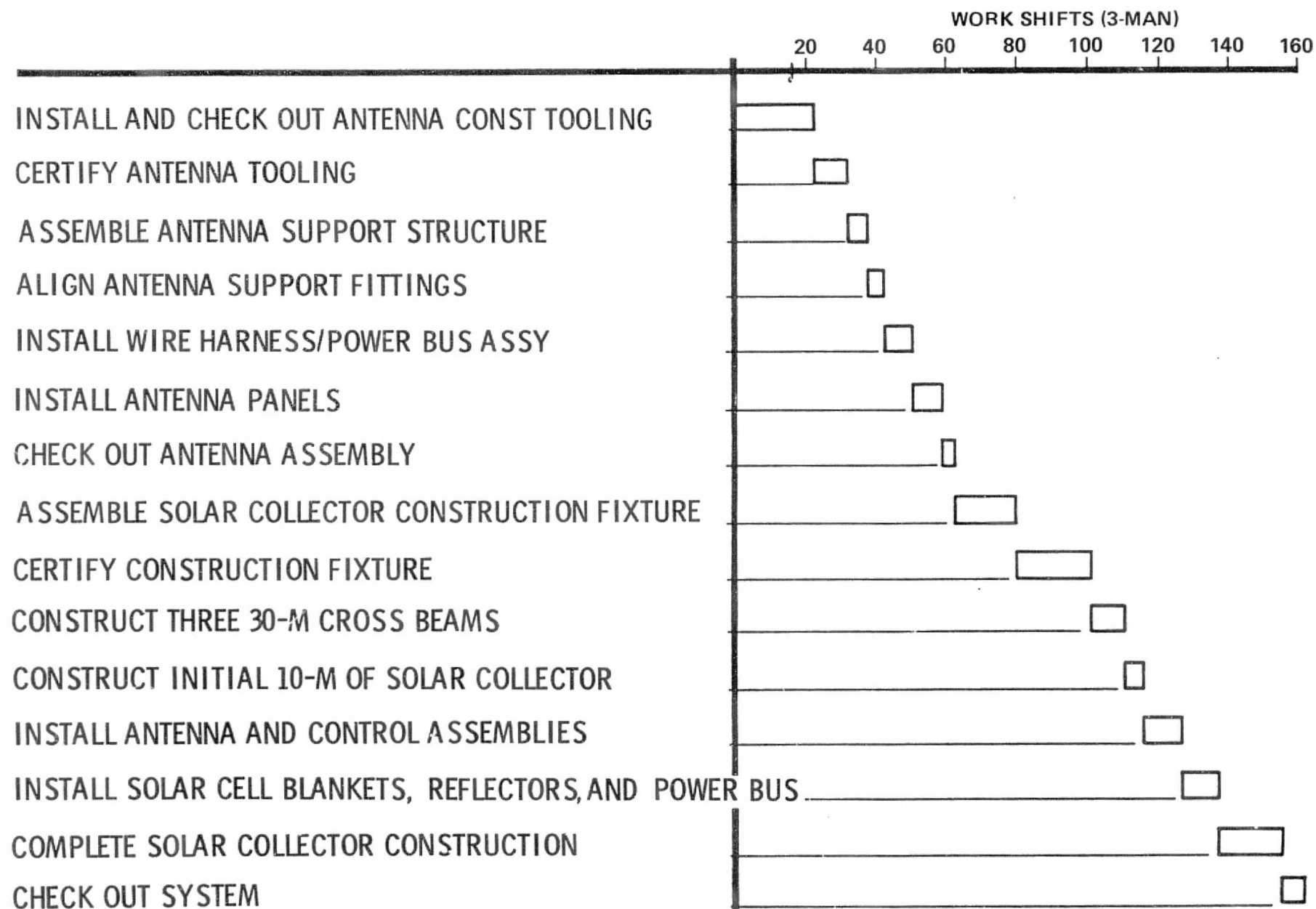


Figure 2.1.3-11. SPS TA-2 Construction Timeline



of a solar collector and a microwave antenna and rotary joint. In this process, a number of other test requirements can be met as indicated in Table 2.1-3, Section 2.1.

Table 2.1.3-2 shows the relevance of the Table 2.1-3 development requirements to the solar collector and the microwave antenna/rotary joint. Items that have the most impact on the SCB technical requirements have been emphasized. The primary solar collector items listed in the table are discussed below.

The primary development requirements of the TA-2 solar collector include (1) development and demonstration of orbital construction techniques typical of those to be used in construction of a full-scale prototype, (2) evaluation and operation of the completed solar collector in support of microwave power transmission tests, and (3) evaluation of space plasma effects. The test requirements listed in Table 2.1.3-3 have been identified to fulfill these objectives.

The matrix of Table 2.1.3-4 shows what TA-2 tests will be required to satisfy the six development requirements established in Section 2.1 (see especially Table 2.1-1). The test requirements and the rationale for test selection are discussed below under numbered headings that correspond to the numbered development requirements of Table 2.1.3-4. The tests themselves are discussed in a subsequent section titled Test Descriptions. Again, the subsection headings are numbered to correspond with the numbered subjects in the Test Descriptions column of Table 2.1.3-4.

#### 1. Space Construction of Large Structures

As in the case of the solar collector, a primary objective of antenna structure testing is to develop data on the feasibility and cost of constructing very large structures on orbit. Antenna structure testing is critical since the dimensional stability requirements are exceptionally stringent and large transient temperature gradients are expected. Since the antenna structure uses thin-wall composite tubing (with thermal expansion coefficients near zero) similar to that required for the SPS model, the structure should be constructed on orbit to develop the necessary data.

Table 2.1.3-2  
TA-2 TEST REQUIREMENT MATRIX

Development Requirements	Solar Collector	Antenna/ Rotary Joint
1. Evaluate Space Construction of Large Structures		
A. Solar Collector	P	
B. Microwave Antenna		P
C. Structural Interfaces	S	P
2. Evaluate Large-Scale Energy Collection and Distribution		
A. 20,000 V	P	
B. Switching	P	
3. Evaluate Large-Scale Microwave Transmission and Control		
A. Ionospheric Degradation of Phase Control System		
B. Thermostructural Effects on Phase Control System		P
4. Evaluate RFI Effects		
A. Direct Transmission from Amplitrons		P
B. Switching and Rotary Joint Sources	S	P
C. Voltage Level Regulation		P
D. Ionosphere-Induces		
5. Space Plasma Effects		
A. Arcing and Leakage	P	P
B. Spacecraft Charge Phenomena		
6. End-to-End Functional Verification		
A. Thermal/Structural Interaction	S	P
B. Phase Control System		P
C. Power Transfer/Rotary Joint Current Density	S	P
D. Prototype Manufacturing/Assembly Processes	S	P

P = Primary Requirements  
S = Secondary Requirements

Table 2.1.3-3  
TA-2 SOLAR COLLECTOR TEST REQUIREMENTS

---

I. Space Construction of Large Structures

- A. Construction procedures and productivity
- B. As-built alignment accuracy as a function of temperature
- C. Evaluation of deflection, stress and strength characteristics
- D. Structural dynamics

II. Large-Scale Energy Collection and Distribution

- A. Collector output voltage, power, and efficiency as a function of temperature, orientation, and orbital life
- B. Solar cell blanket and mirror attachment performance and life
- C. 20,000-V operation and switching
- D. Maintenance and repair procedures
- E. Mirror and blanket optical performance

III. Space Plasma Effects

Leakage currents through the space plasma as a function of voltage and life

---

Space construction-related test requirements largely consist of initial calibration and an evaluation of the quality and performance of the space-constructed product in the LEO environment; specifically, as-built accuracy and mechanical alignment, thermal stability, and structural dynamics (inertial and thermal) are of interest.

Construction of a large microwave transmission system that must retain a high-power transmission efficiency and hold spurious radiation, leakage, and sidelobe energy to an absolute minimum imposes severe mechanical and electrical tolerances on the system assembly, alignment, and calibration. Economical construction of such a system in space requires evaluation of special test equipment, fixtures, and time-consuming subassembly alignment and calibration procedures. Accordingly, the proposed space construction

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Table 2.1.3-4  
TA-2 DEVELOPMENT AND TEST SUMMARY

Test Descriptions (Tests and Variables)	SPS Development Requirements (Reference Table 2.1.3)					
	1. Space Construction of Large Structures	2. Energy Collection and Distribution	3. Microwave Transmission and Control	4. RFI Effects	5. High Voltage and Space Plasma Interaction	6. End-to-End Functional Verification
1. Space Construction						
A. Longeron and strut structure fabrication	X	X				
B. Antenna structure assembly	X	X				
C. Structure, waveguide sections, and power module assembly	X	X				
2. Antenna Alignment, Calibration, and Test						
A. Assembly, alignment, and calibration procedures verification	X	X				
B. Voltage standing wave ratio measurements	X	X				
C. Mechanical alignment test	X	X				
D. Relative phase measurements between critical points	X	X	X			X
E. DC power	X		X		X	
3. Radiation Pattern						
A. Pointing angle			X	X		
B. Temperature			X	X		
C. DC power			X	X		
D. Frequency				X		
4. Efficiency						
A. Pointing angle						X
B. Temperature						X
C. DC power						X
D. Frequency						X
5. Pointing Accuracy						
A. Pointing angle			X			X
B. Temperature			X			X
C. DC power			X			X
6. Stability						
A. Pointing angle	X					X
B. DC power	X					X
7. Spurious Radiation						
A. Temperature				X	X	X
B. Frequency				X	X	X
C. Spherical look angle				X	X	X
8. Solar Collector Operation and Performance						
A. Load/Source Switching		X		X	X	X
B. Orientation/Sun Angle		X		X	X	X
C. Temperature/Temperature Cycling		X		X	X	X
D. Life		X			X	X
E. Maintenance and Repair		X				

methodology will be verified by constructing an abbreviated system (TA-2) in LEO before finalizing the fabrication, assembly, alignment, and calibration procedures and fixtures for constructing a full-scale microwave power transmission system in space.

## 2. Energy Collection and Distribution

The completed solar collector will be evaluated and operated in support of the microwave antenna transmission tests. Collector output voltage, power, and efficiency will be measured as functions of temperature, orientation, and orbital life. Solar cell blanket and mirror attachment performance and life will be determined. The collector's capability to collect and distribute large amounts of energy will be tested. Maintenance and repair procedures will be validated.

## 3. Microwave Transmission and Phase Control

Evaluation of the microwave power transmission, beam forming, and beam steering capability in a benign space environment requires static main lobe pattern measurements and dynamic pointing accuracy measurements, supplemented by phase control and power data from appropriate test points. In order to separate the beam forming and beam steering phase control problems, the pattern tests must be conducted under both steered and non-steered conditions.

## 4. RFI Effects

The RFI effects of the SPS that must be evaluated to determine environmental impact and corrective action are separated into in-band and out-of-band spurious radiations. The in-band power (2.45 GHz) is normally ignored in a transmission system. However, due to the extremely high power levels of the SPS, these spurious radiations through antenna sidelobes, antenna grating lobes, and leakage from microwave components may exceed the off-frequency rejection capability of other S-band equipment. The out-of-band spurious radiation (e.g., harmonics, noise, and arcing) must also be thoroughly evaluated.

To evaluate the in-band RFI effects, spherical radiation patterns must be obtained under various beam steering, temperature, and power conditions

since these factors have a major impact on the antenna side lobe and grating lobe structure.

Evaluation of the out-of-band RFI effects requires that field strength measurements be obtained across the spectrum and measured spectral density be mapped in a complete sphere about the antenna.

#### 5. Space Plasma Effects

The arcing and leakage associated with high-voltage structures and components must be evaluated to determine the extent of the problem and the corrective action needed.

#### 6. End-to-End Functional Verification

The overall system functional performance must be verified over the range of LEO environmental conditions, and data must be collected for use in accurately predicting performance and producing design solutions associated with the full-scale power transmission system at GEO.

To maintain radiation efficiency and minimum side-lobe levels from the antenna requires that phase integrity be retained between radiating slots on the array. Since the waveguide propagation velocity is sensitive to temperature and the amplatron phase shift is sensitive to temperature, frequency, and power, operation in the space environment (including earth shadowing) with a power-weighted aperture imposes severe design requirements in order to maintain frequency and phase integrity of the antenna alignment. Design verification in a space environment of the frequency-phase sensing and control circuits is required to minimize pattern degradation. The verification will include monitoring the temperature gradients and the corresponding spread in resonant frequency (phase) across the array in order to evaluate the uncompensated defocusing effects applicable to the full-scale array.

Verification of the mechanical steering accuracy obtainable over the entire range of environmental conditions in space is necessary to ascertain the electronic steering limits over which specified performance is to be required. The electronic steering accuracy and radiation efficiency as a function of

off-boresight steering conditions must be determined to evaluate the adequacy of the system design and establish necessary upgrades.

#### Test Descriptions

The tests to be conducted to satisfy the test requirements noted in the preceding section, and summarized earlier in Tables 2.1.3-2 through 2.1.3-4, are briefly described here.

##### 1. Space Construction

The test phase on all construction fixture equipment occurs during its check-out and certification prior to its use in constructing mission hardware. Table 2.1.3-5 outlines solar collector construction fixture test procedures. It should be noted that while these are written in series form, they would be met in a single "all up" test procedure. This form of test is considered feasible since all components will have been thoroughly tested prior to erection in space. The antenna assembly fixture test procedures are similar to those outlined in Items II and III of Table 2.1.3-5.

The construction processes, procedures, and productivity will be evaluated by measuring key performance parameters (e. g., crew time for specific operations) while constructing the solar collector.

While as-built dimensional accuracy of the solar collector is of primary interest, a survey of the collector to the accuracy desired will be difficult since the structure will be in constant dynamic motion. Isolation of the dynamic motion is further complicated since it will occur because of both cyclic inertial loads (attitude control system) and thermal loads (90-minute light/dark cycle). Thus determination of the isothermal load-free as-built shape requires inertial and thermal instrumentation as well as accurate determination of shape — and all measurements must be time-correlated. This instrumentation will, however, allow complete measurement of structural dynamics. Item I of Table 2.1.3-6 outlines the planned solar collector tests with respect to space construction.

Table 2.1.3-5

SOLAR COLLECTOR CONSTRUCTION FIXTURE CHECKOUT AND  
CERTIFICATION TEST OUTLINE

---

- I Roll-Forming Machines and Associated Welding
    - A. Fabricate short lengths of beam caps simultaneously from all six machines and test response to open-loop control signals.
  - II Truss Assembly
    - A. Test both robots' ability to place truss members in all positions (fixed beam caps).
    - B. Test all attach heads by passing truss/cap junctions through head (beam caps in motion).
  - III Control System
    - A. Test intrabeam closed-loop control system by constructing short lengths of beams on both sets of machines. Introduce artificial error signals to check response.
    - B. Test interbeam control system by constructing short lengths of beams simultaneously on both sets of machines.
  - IV Reflector and Solar Blanket Deployment and Attachment
    - A. Using limited rolls of reflector and simulated blanket materials, test procedures, installation, and initial manual attachment of surface ends to beam structure.
    - B. Test all automated attach heads by simultaneous construction of both beams and deployment of reflectors and blanket.
    - C. Verify construction rate/power estimates and experimentally determine maximum practical construction rate.
  - V Salvage and Repair Procedures
    - A. Develop and test procedures for repairing failed construction fixture equipment used in the following activities:
      - 1. Roll forming
      - 2. Cap welding
      - 3. Robot operation
      - 4. Truss attachment
      - 5. Reflector/solar blanket deployment
      - 6. Reflector/solar blanket attachment
-



Table 2.1.3-6  
SOLAR COLLECTOR TEST OUTLINE

---

- I. Space Construction of Large Structures - Alignment and Dynamic Shape Determination
    - A. Optical/photographic determination of shape as a function of time
    - B. Sufficient temperature sensors to allow estimate of temperature distribution in beam caps
    - C. Sufficient inertial instrumentation to allow estimate of dynamic inertial loads
    - D. Sufficient strain gages to evaluate stress/strength characteristics
    - E. Test procedures to include holding the collector in different fixed attitudes for several orbits.
  - II. Large-Scale Energy Collection and Distribution
    - A. Operate the solar collector at various loads and voltages by means of switching antenna and solar array sections, and using various sun angles. Measure voltages, currents, blanket and structure temperatures and orientation. Also, obtain visual/optical and photographic data on reflector and blanket ripples and attachment performance. Repeat the test 6 months, 1 year, and 2 years later.
    - B. Orient the solar collector to black space and perform maintenance and repair procedures on the blanket, reflector, and switches.
  - III. Space Plasma Effects
    - Conduct as part of IIA.
- 

2. Antenna Alignment, Calibration, and Test

The proposed antenna consists of 4,320 slotted 0.5-m waveguide radiators formed into 15 subarrays of 288 horizontal slotted waveguide sections employing a series-parallel amplification-feed network. For proper operation under non-beam-steering conditions, each of the 4,320 waveguide radiators must be energized in phase at the resonant frequency of the slotted radiators. Since the radiator resonant frequency is environment-dependent and the amplifier phase shift is environment-, frequency-, and power-sensitive, automatic phase sensor and control electronics must be employed and evaluated. Consequently, the calibration and alignment procedures of this equipment are

critical and the techniques and equipment needed to perform this task in space require verification. In addition, the calibration and alignment procedures for the phase-steering sensors and controls need to be verified under space conditions.

Maintaining radiation efficiency and minimum side-lobe level from the antenna requires retaining phase integrity between each pair of radiating slots on the array to the accuracy required by efficiency and RFI considerations. Since the wave guide propagation velocity is temperature-sensitive and the amplitron phase shift is temperature, frequency, and power sensitive, operation in a space environment, including earth shadowing, with a power-weighted aperture imposes severe design requirements to maintain frequency and phase integrity of the antenna alignment. Design verification in a representative space environment is required on the frequency-phase sensing and control circuits to assure acceptable pattern degradation. This verification will include monitoring the temperature gradients and the corresponding spread in resonant frequency across the array in order to evaluate the phase correction as well as the uncompensated defocusing effects applicable to the full-scale array.

#### Antenna/Rotary Joint - Large Structures Space Construction

Antenna test procedures are similar to those of Item I in Table 2.1.3-6 presented earlier for the solar collector tests.

### 3. Radiation Pattern

The main lobe and hemispherical side lobe radiation patterns of Test Article 2 will be obtained using either of two Beam Mapping Satellites (BMS-QC and BMS-C) operating in antenna pattern test range configurations. The BMS-QC operates in the same orbit as the SCB at a range 3.4 km from TA-2 at the near edge of the antenna far field where the beam is properly formed; BMS-C mapping is also 3.4 km from the test article. The co-orbital BMS instrumentation will determine the two polarization power levels and telemeter these data to the SCB in real time. Correlation of these data with TA-2 optical instrumentation as the array is rotated to sweep the beam past the BMS will create the desired antenna patterns.

The beam mapping test procedure is the same for TA-2 as for TA-1. The procedure for TA-1 is illustrated in Figure 2.1.3-12. The line from the center of TA-1 to the center of the BMS is the geometric normal to the TA-1 antenna. Operation of the BMS pilot beam steers the beam electronically toward the BMS and focuses the beam on the BMS.

The first of two main test procedures (pilot beam on) records the pilot beam signals (phase angle) for each antenna subarray while steering and focusing. The recorded phase-angle signals will include, for example, compensation for TA-2 antenna distortion.

The second procedure (pilot beam off) involves the playback of the recorded signals to maintain the focus and steering line of sight while rotating the TA-2 antenna through an angle of  $\pm\beta$  (rotation through an angle  $\beta$  about the vertical arm to the dotted position). This rotation sweeps the beam past the BMS, which measures field strength, to produce data for a beam plot. This represents a "slice" through the beam for a given beam steering angle.

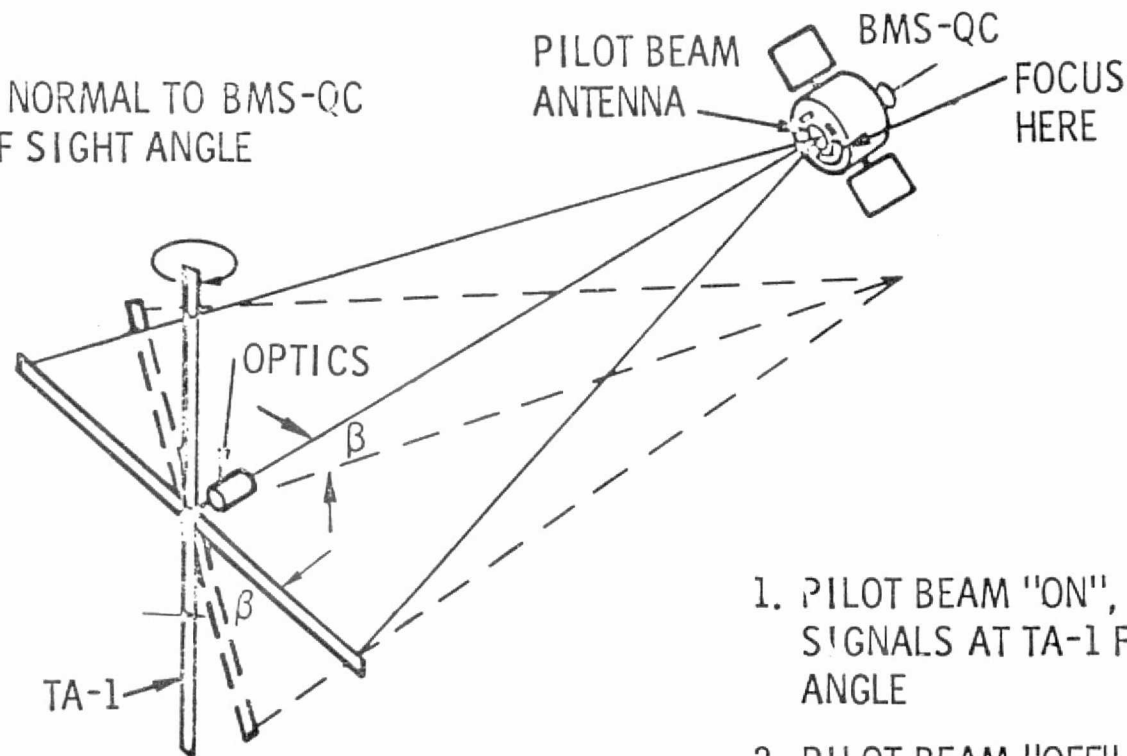
The procedure discussed above is repeated for various electronic beam steering angles, which are obtained by rotating the antenna through some angle and electronically focusing the beam on the BMS with the pilot beam on. The appropriate data are recorded for playback to "freeze" the pattern while sweeping through  $\pm\beta$  for the next "slice."

It is assumed that  $\beta$  and the steering angle are both in a single horizontal plane; this is a simplified representation of a multiplane situation, and the same approach is used in a number of planes. In-band and out-of-band RFI are measured at angles of  $\pm 180$  deg about the antenna by putting the BMS in an elliptical orbit so it traces a path around the SCB. Out-of-band RFI is measured at approximately 1 km while in-band RFI is measured at ranges up to the 258 km.

#### 4. Efficiency

Efficiency data will be obtained by instrumenting the TA-2 microwave system to record voltage and power at the prime power input and selected critical

$\beta$  = ARRAY NORMAL TO BMS-QC  
LINE OF SIGHT ANGLE



1. PILOT BEAM "ON", RECORD PILOT BEAM SIGNALS AT TA-1 FOR FIXED STEERING ANGLE
2. PILOT BEAM "OFF", PLAY BACK RECORDED SIGNALS TO MAINTAIN FIXED STEERING ANGLE
3. ROTATE TA-1 THROUGH ANGLE  $\beta$  & RECORD FIELD STRENGTH IN BMS-QC
4. REPEAT FOR VARIOUS STEERING ANGLES

TEST ITEM	RANGE (km)	$\beta$ (DEG)
1. TA-1 BEAM MAPPING	258	$\pm 5$
2. TA-2 BEAM MAPPING	3.4	$\pm 10$
3. TA-1 & TA-2 RFI	1-258	$\pm 180$

Figure 2.1.3-12. Beam Mapping Test Procedure

points throughout the power transmission system, then correlating these data by analysis with the corresponding radiation patterns and received power level data.

#### 5. Pointing Accuracy

Static pointing accuracy is obtained by data reduction on the Radiation Pattern Tests under various off-array-normal steering conditions. However, these data will be verified under dynamic steering conditions by activating the pilot pulse system and mechanically performing a slow raster scan of the array as the pilot pulse subsystem maintains beam alignment. The recorded phase commands at the array and power level variations from the mapping satellite, when corrected for antenna gain variations, are translated to pointing error and compared with the static error data.

#### 6. Stability

The TA-2 will be instrumented to measure and record deviations in the transmitter frequency over the range of temperature and dc power conditions imposed by the space environment. These data will be correlated with the radiation pattern and efficiency data.

#### 7. Spurious Radiation

In addition to the side lobe and grating lobe data obtained from the hemispherical pattern test data, field strength data of arcing, noise, and harmonics will be obtained using BMS instrumentation. These data must be supplemented with data on the field strength about the TA-2 station to determine whether any EMC problems exist with the SCB electronics.

The system initially will be checked out by starting with the minimum voltage, then slowly increasing it to full power operating conditions, all the while monitoring for arcing or excessive leakage.

#### 8. Solar Collector Operation and Performance

These tests will be conducted to obtain data on the solar collector's ability to collect and distribute large amounts of energy. The collector will

be operated at various loads and voltages by switching antenna and solar array sections and using various sun angles. Voltages, currents, and blanket and structure temperatures and orientations will be measured. Reflector and blanket ripple and attachment performance data will be obtained using visual as well as optical and photographic methods. These tests will be repeated in 6 months, 1 year, and 2 years.

Maintenance and repair of the blanket, reflector, and switches will be done with the collector oriented to black space.

Space plasma effects testing will be conducted in conjunction with the energy collection and distribution tests.

#### 2.1.3.4 Space Construction Base Requirements

The requirements imposed on the SCB by TA-2 and its operations are summarized in this section.

### Special Devices

#### Solar Collector Construction Fixture

The TA-2 automated solar collector fabrication and assembly fixture design, Figures 2.1.3-13 and 2.1.3-14, is based upon the SPS prototype construction system. This concept continuously produces a completely finished solar collector in a fully automated "assembly line." Roll-forming machines and associated projection welders for the 10-m beam caps are located in unpressurized thermal control shrouds. Six of these are mounted on a jig frame to simultaneously produce the required longeron caps. Two robots, mounted on the jig's main beam, pick up prefabricated truss tubes from a spring-fed magazine and clip them to the emerging beam caps. As the truss/cap junction passes through a truss attach head, a structural bond is formed (projection weld, large-diameter hollow rivet, or one of several other viable options).

Pretensioned reflector and solar cell blanket materials are continuously deployed from rolls mounted between the jig frame arch and main beam and

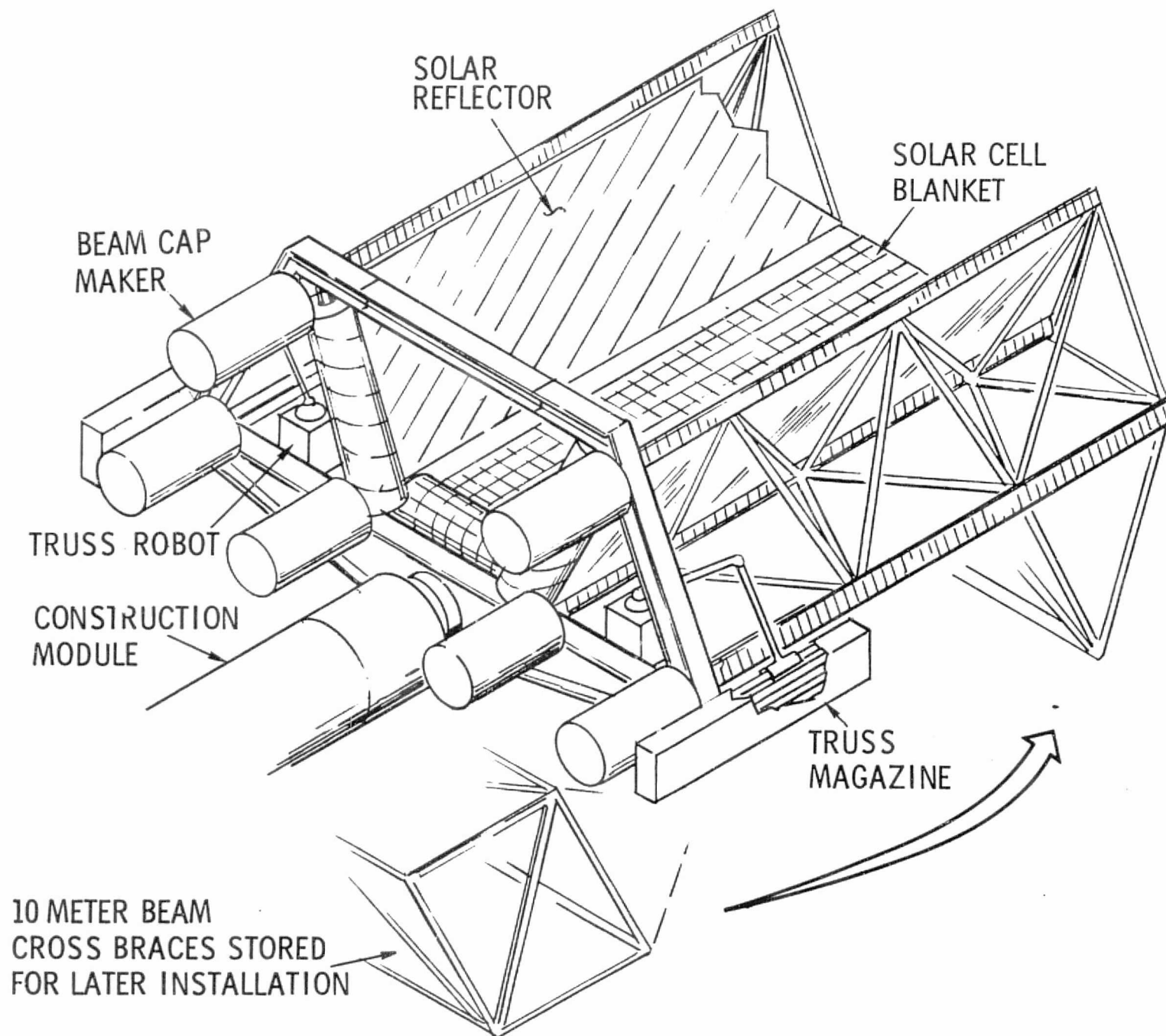


Figure 2.1.3-13. SPS TA-2 Fabrication and Assembly

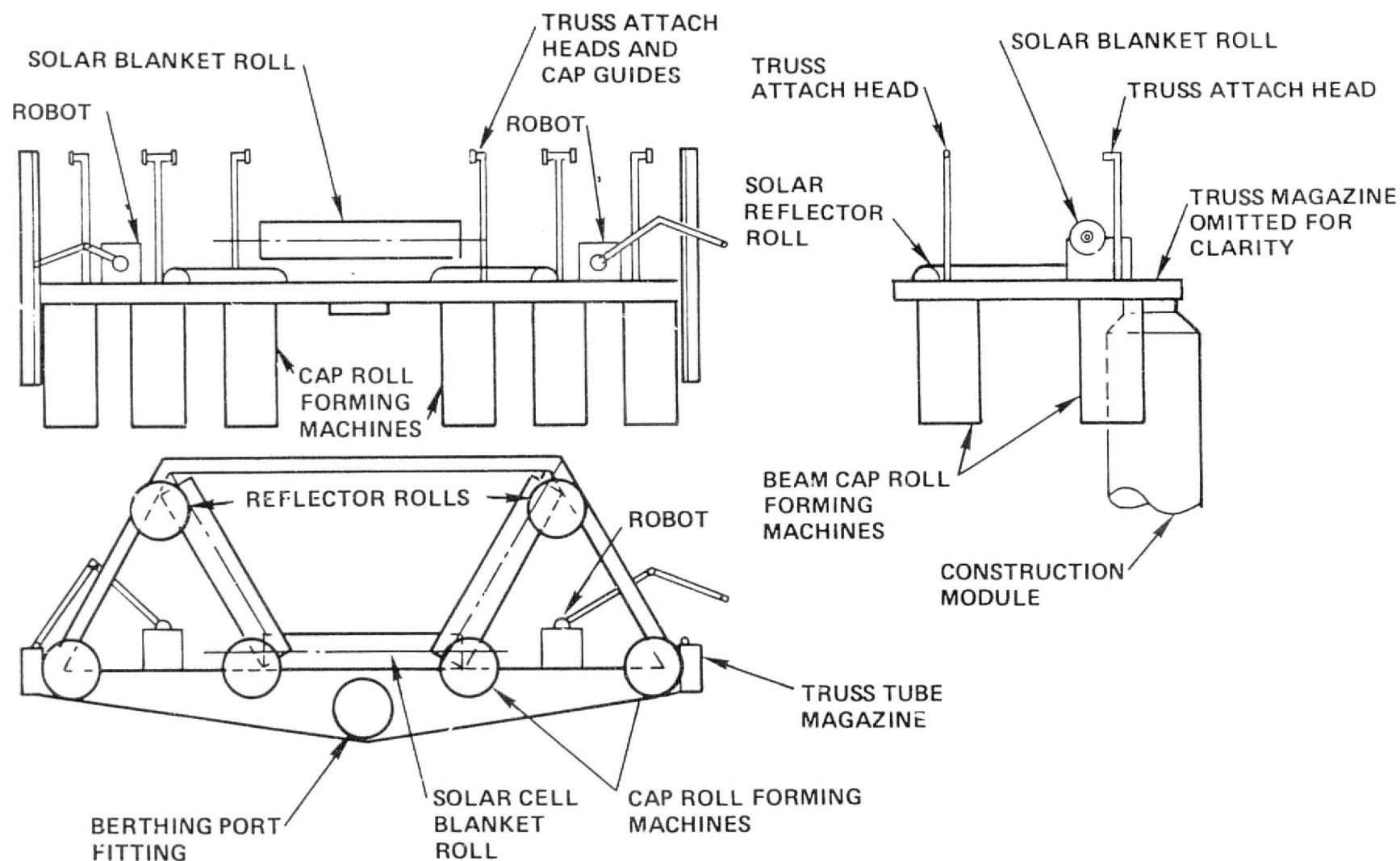


Figure 2.1.3-14. Automated Construction Fixture for Solar Collector



on the main beam, respectively. Reinforced edges of reflector sheets are attached to the beam cap flanges by staples or blind rivets. However, the heavier solar cell blanket material would induce extreme stresses into the beam caps during light/dark thermal cycling if it were rigidly attached. Blanket edges are therefore suspended from the beam caps by constant force springs.

Prior to beginning fabrication of the longerons, the construction fixture is used to produce three 30-m lengths of 10-m beams. These are stored under the construction module and used, as needed, for structural cross members in the collector. These large members are attached to the emerging longerons using the mobile crane and EVA.

Electrical power required by the fixture is a linear function of cap deployment rate; it is estimated to be approximately 15 kW/m/min (exclusive of lighting requirements). Since deployment of the full TA-2 solar array in one week implies an average rate of only 0.026 m/min, average power consumption is quite low.

Figure 2.1.3-14 shows three views of the TA-2 automated solar collector construction fixture. Note that a berthing port fitting on the main beam allows the fixture to be attached to the construction base. A mass summary for the solar collector construction fixture is presented in Table 2.1.3-7. Two Shuttle flights are required to deliver all elements of the fixture.

#### Antenna Assembly Fixture

The function of the TA-2 antenna assembly fixture is to demonstrate the automated assembly of prototypical composite structural components (graphite/polyimide thin wall tubing 15 cm in diameter) in a continuous-flow process.

The automated antenna assembly fixture for TA-2, Figure 2.1.3-15, consists of seven tube feeds positioned on a jig frame so that the antenna longerons can be simultaneously deployed. Strut attach fittings are thermally bonded to the longerons by a device immediately downstream of each tube feed. Three programmed robots, mounted on the fixture frame among the

Table 2.1.3-7

## TA-2 SOLAR COLLECTOR CONSTRUCTION FIXTURE MASS SUMMARY

		Mass (kg)
Fixture Frame	1,957	
Frames		1,357
Fittings		600
Beam Cap Machines (6)	5,442	
Docking Provisions/Tunnel	771	
Automatic Robots (2)	1,360	
Checkout and Support Provisions	550	
Stowage and Material Support (5%)	500	
Subtotal	10,530	
Contingency (25%)	2,633	
Total	13,163 kg (29,018 lbm)	

upper four longerons, place the tubular struts against these fittings where they are attached by thermal bonding or hollow rivets.

This entire fixture is transported as a fully assembled entity that occupies approximately two-thirds of the cargo bay. The berthing port shown in Figure 2.1.3-15 allows the fixture to be attached to the construction base. A mass summary is presented in Table 2.1.3-8.

Table 2.1.3-8

## TA-2 MICROWAVE ANTENNA ASSEMBLY FIXTURE MASS SUMMARY

		Mass (kg)
Fixture Frame	1,837	
Robots (3)	2,040	
Attachment Mechanisms (7)	350	
Checkout and Support Provisions	250	
Stowage and Material Support	224	
Subtotal	4,701	
Contingency (25%)	1,175	
Total	5,876 kg (12,954 lbm)	

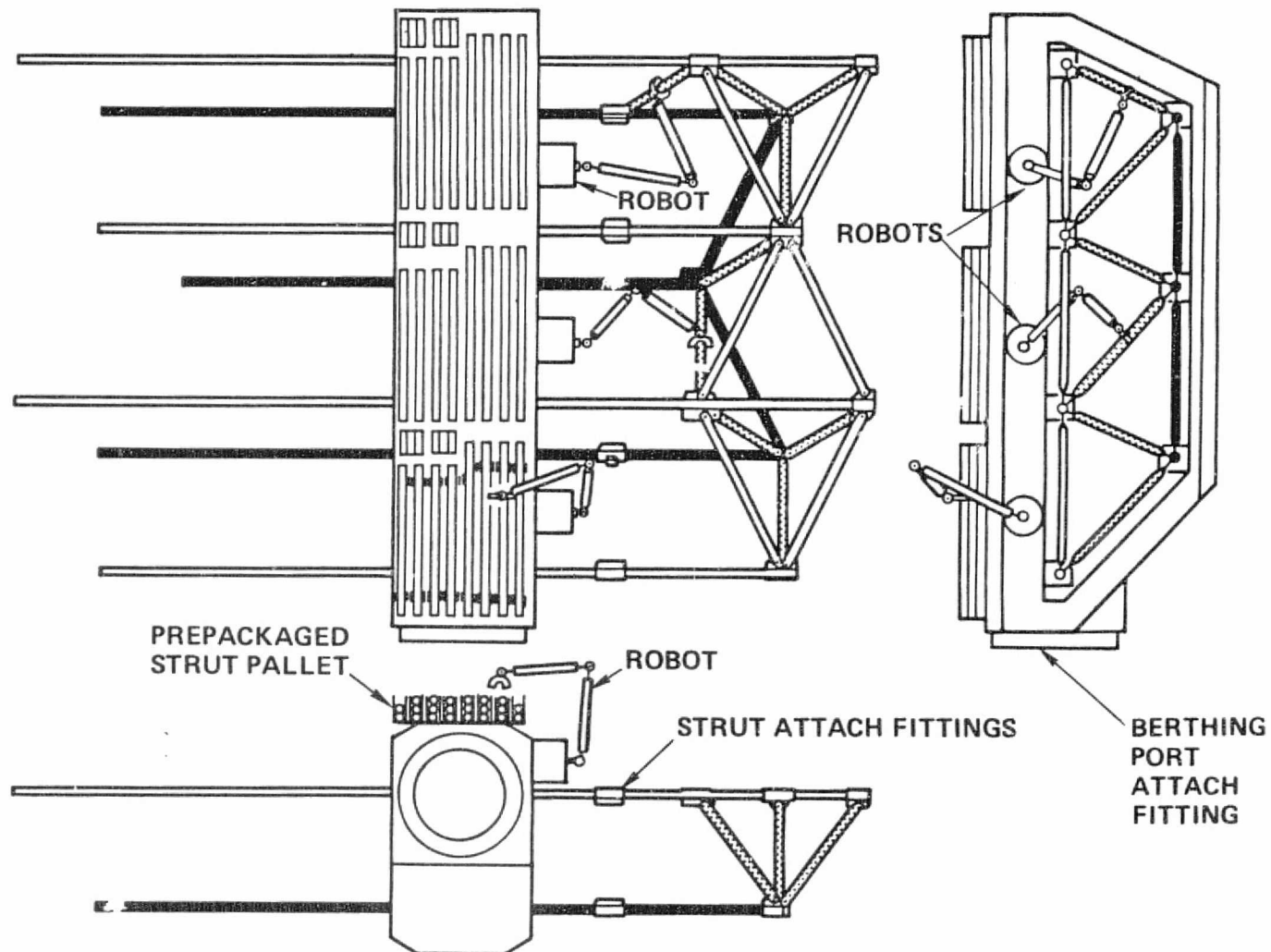


Figure 2.1.3-15. Antenna Assembly Fixture

Use of adjustable positions for the robots and longeron tube feed guides, together with interchangeable parts for different longeron cross sections, allows the TA-2 automated antenna structure assembly fixture to be adapted to TA-1 (as noted in Section 2.1.1).

The prototype antenna structure manufacturing concept would include simultaneous fabrication and assembly (as is the case with the solar collector). However, this would involve considerable costs in TA-2 tooling since seven tube fabrication modules could be required. For this reason the requirements call for tubing fabrication to be separated from assembly of the truss structure.

#### Composite Tube Fabrication Module

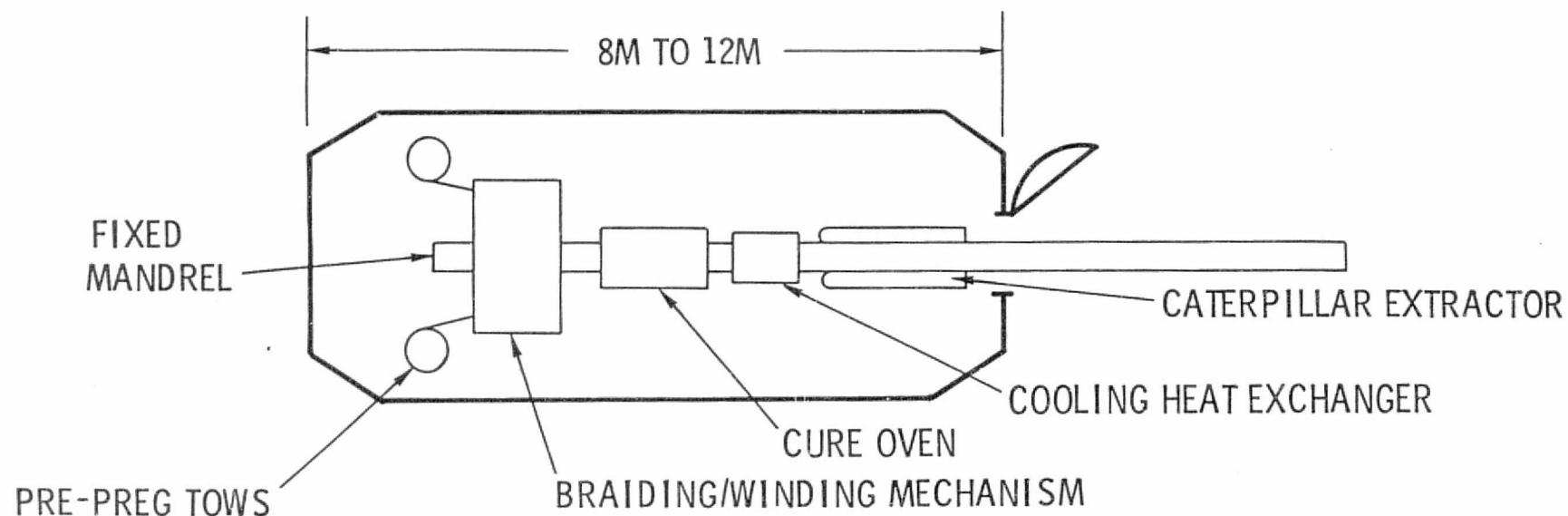
This concept is a hybrid (Figure 2.1.3-16) that combines the MDAC-developed carrier braider with features of commercially available pultrusion machines. The braider continuously lays prepregged tows on a fixed mandrel. This layup is cured as it is propelled through an oven by the caterpillar extractor (the cooling heat exchanger is necessary for rapid production). Thus the process is continuous. To facilitate production of long tubes, the module is evacuated and opened after initial setup is accomplished in a shirtsleeve environment. Vacuum operation is feasible because the process utilizes only prepregged tows.

The fixture is capable of making constant-thickness or isogrid circular tubes from 5 to 150 cm in diameter. It is also capable of making noncircular cross section tubes and weaving complex three-dimensional shapes. Tube lengths are limited only by the ability to control the free end. The weight is estimated to be approximately 4,660 kg. Approximately two-thirds of a Shuttle flight is required to deliver the module to the SCB.

#### EVA Support Station

An airlock is required which is capable of accommodating three persons. They include a crew of two in transfer to and from EVA plus an additional person, if necessary, to assist the crew in their preparation for or return from EVA. The required airlock volume is  $10 \text{ m}^3$ , providing for pressurization and depressurization, emergency breathing support, and denitrogenation.

An adjacent  $67 \text{ m}^3$  facility is required for EVA equipment charge and recharge, cooling, equipment checkout and donning, suit and tool storage, and suit reconditioning.



#### FEATURES:

- 1 COMBINATION BRAIDING, WINDING, AND HORIZONTAL FIBER LAYUP MECHANISM SIMILAR TO MDAC DEVELOPMENT ALLOWS VERSATILITY
- 2 FIXED MANDREL AND CATERPILLAR EXTRACTOR SIMILAR TO COMMERCIAL "PULTRUSION" MACHINES ALLOWS CONTINUOUS PRODUCTION OF VERY LONG TUBES

Figure 2.1.3-16. Composite Tube Fabrication Module Concept

### Crane/Manipulator

The SCB must provide a crane or manipulator with two arms able to reach all extremities of the solar collector construction fixture (reference Figure 2.1.3-14). The required length is 35 m.

### Mobility Devices

Devices may be required to transfer equipment and crewmen beyond the reach of the crane/manipulator for purposes of assembly, checkout, and/or servicing.

### Power

The power required from the SCB during construction will average 9 kWe, with a peak of approximately 12 kWe. During testing, average and peak power required will be approximately 2 and 4 kWe, respectively, since the solar collector will provide most of the required power.

### Control Center

Equipment for remotely monitoring and controlling the automated construction processes must be centralized in an SCB control center. The equipment will include closed-circuit TV monitors for each fabrication and assembly function. During test, the control center must be equipped to monitor, display, and evaluate TA-2 functional parameters (e.g., antenna geometric pointing and electronic steering angles).

A command transmitter and associated controls will be required to command TA-2 and BMS operations. Display capability (TBD) will also be needed (not continuous; stored information used). Display data will include, for example, BMS position and rate information. The SCB caution and warning system will provide safety support for the TA-1 missions. For instance, a warning would be signalled if the BMS got too close to the antenna and SCB.

The BMS will be tracked using a range-only microwave radar and two cameras — boresight and tracking. The radar will be used to determine BMS range to an accuracy of  $\pm 2$  m. The boresight camera measures the angle from the antenna geometric axis to within 1 sec. It is a long-focal-length time-lapse 20-cm optics camera mounted on the TA-1 antenna. Zoom lens video provides control center display. Computer processing of video

information measures angles to within 1 mrad. Film development and reader equipment will be required aboard the SCB to support measurement of TA-1 angular displacements. The tracking camera provides video during RFI testing for measuring large BMS angular displacements from the antenna axis to an accuracy of  $\pm 8$  mrad.

#### Data and Communications

TA-1 requires the following capabilities:

<u>Activity and Item</u>	<u>Data Rate or Bandwidth</u>
Construction	TBD
Data link	
(Other, TBD)	
Test	TBD
Command	
Instrumentation	
Beam Mapping Satellite	
(Other, TBD)	

#### Electromagnetic Interference Control

The SCB must be designed so that its operation cannot be interfered with by TA-2 operation.

#### Berthing

Provisions must be made for berthing:

- A. TA-2 during construction, test, and post-test storage
- B. TA-2 construction fixtures (solar collector and antenna) during and following construction
- C. Logistic modules as follows:
  1. Construction fixtures (2 2/3 modules)
  2. Tube fabrication module (~2/3 module)
  3. Construction supplies and materials (~1 module)

#### Orientation

During construction, it may be necessary to point the longitudinal axis of the solar collector to the sun in order to minimize thermal distortions. It may also be necessary for the solar collector to either face black space during construction or be provided with a solar shroud to minimize array output.

Because either requirement would significantly affect the attitude control of the SCB, further study and trades are required.

During test operations, the plane of the solar collector must be oriented normal to the solar flux while the plane of the antenna must be oriented normal to the velocity vector. These orientations must be maintained through two orbits each day for six months.

#### Environmental Control

Temperature, humidity, and cleanliness requirements for the control center are the same as for SCB shirtsleeve activity.

#### Acceleration

To minimize weight and cost, lightweight structures are used to support the collector and antenna. Accelerations must be maintained below  $\sim 1.0$  g to avoid overstressing these structures.

#### Contamination

Effluents, outgassing, and propulsion products must not impinge on or form clouds ( $\text{TBD particles/cm}^3$ ) about the amplitrans in order to preclude arcing. Also, impingement on the deployed TA-2 solar array is to be avoided.

#### Safety

Field strength measuring devices of TBD sensitivity will be strategically located aboard the SCB to monitor and measure the microwave doses the crew is being exposed to. This will help assure that dose limits are not exceeded.

#### Workshop

TA-2 construction and test will require the use of a pressurized general purpose workshop for maintenance and repair of equipment. Approximately  $20 \text{ m}^3$  will be required.

#### Logistics

A total of approximately 4-1/3 Shuttle flights to orbit are required for TA-2 construction in accordance with the breakdown under "berthing" above. TA-2 will not require scheduled maintenance. Periodic unscheduled servicing (including modular replacement of failed elements) will be required during the operating life of TA-2.



### Personnel

The SCB must provide personnel as follows:

<u>Item</u>	<u>Crew Size</u>	<u>No. of Shifts</u>
Assembly and checkout of fixtures	3	68
Construction	3	92
Test/evaluation	2	730

### Warehousing

Approximately 220 m<sup>3</sup> of external storage volume must be maintained aboard the SCB for temporary storage of TA-2 parts unloaded from the Shuttle during construction. This volume is in addition to berthing and storage requirements for TA-2 tooling and fixtures and temporary storage of three 10-m beams 30 m long.

### Scrap Control

A method will be required for controlling, storing, and disposing of scrap materials resulting from fixture checkout and TA-2 fabrication.

## 2.2 SPACE PROCESSING

Space processing may ultimately provide commercially significant sources of unique and valuable products not producible at competitive costs on earth. The long-term reduced gravity experienced on a space platform minimizes or eliminates gravity-induced phenomena (e.g., convection and sedimentation) that hamper or preclude certain processes from taking place on earth. Likewise, containerless processes, such as levitated melting and heat treating, can eliminate contamination introduced by the crucible.

There are potentially three types of processing: (1) inorganic processing which refers to single crystals, metal oxides, and matrix and composite materials where the basic elements and inorganic compounds are the raw materials, (2) biological processing which refers to working with living matter, and (3) organic material processing. While not prominent in space processing proposals to date and not addressed in this study, organic material processing could be the subject of future space activities. The Space Construction (SCB) provides a wide range of power, mission duration, and manpower support capability. This flexibility is essential for the satisfaction of the diverse support requirements of the variety of candidate space processes.

Three different products have been identified as being illustrative of those having a high potential for development and production in space. These products are urokinase (biological), fiber optics glass, and silicon ribbon (the latter two are inorganics). These products require significantly different processing techniques which are considered to be representative of the spectrum of techniques required by the various candidate processes. The potential use of the Shuttle, Spacelab, and SCB in the evolutionary development of these processes is indicated in Table 2.2-1.

Table 2.2-1  
SPACE PROCESSING OF BIOLOGICAL  
AND INORGANIC MATERIALS

	Shuttle	Spacelab	SCB
R&D			
Bioprocessing	X		
Fiber Optics Glass	X		
Silicon Ribbon	X		
Process Development			
Bioprocessing		X	X
Fiber Optics Glass		X	X
Silicon Ribbon		X	X
Process Optimization			
Bioprocessing			X
Fiber Optics Glass			X
Silicon Ribbon			X
Pilot Production			
Bioprocessing			X
Fiber Optics Glass			X
Silicon Ribbon			X

### 2.2.1 Bioprocessing - Urokinase

#### 2.2.1.1 Mission Overview

Urokinase is an enzyme produced by a small fraction of the cells in human kidneys. It is currently used experimentally as a therapeutic agent active against intravascular thrombi. To produce economic quantities of the material, it is necessary to separate a high fraction of the appropriate cells from a heterogeneous cell mixture and then cultivate them for approximately 30 days. The enzyme is then harvested from the cells, purified, and freeze-dried for storage. Initial experiments indicate that space processing has the potential to improve enzyme production yields by a factor of 300 or more.

Urokinase was selected as a case study for processing in space because it is a semi-continuous flow process whose equipment complement could be representative of many biological material production processes. The approach to processing the enzyme in space as well as the types of equipment utilized in the processing should be applicable to production of other enzymes and complex proteins.

The case example allows for a 90-day interval between Shuttle resupply flights.

The case study results will provide requirements for the Space Construction Base (SCB) power generation and distribution subsystem, the thermal/environmental control subsystem, the communications subsystem, and the control subsystem.

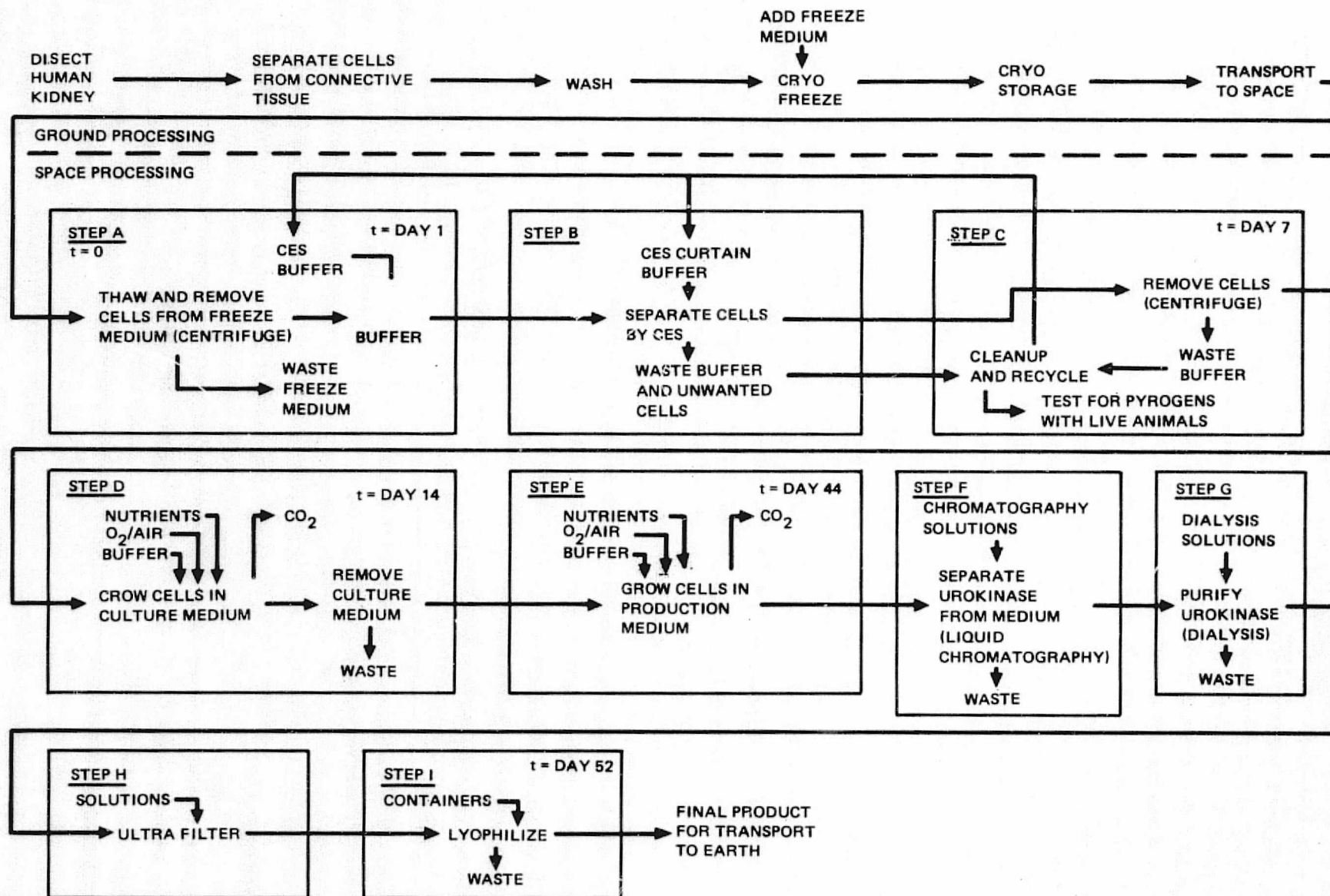
The study will also provide requirements for the bioprocessing module, including the analytic services laboratory and instrumentation. The power, waste heat, data, volume, and weight parameters of the urokinase process development, optimization, and pilot production will be derived from this mission hardware.

#### 2.2.1.2 Process and Mission Hardware Descriptions

Bioprocessing of urokinase, as shown in Figure 2.2.1-1, is divided into the following steps.

- A. CES sample workup
- B. CES operation
- C. Centrifuge/wash
- D. Growth culturing
- E. Production culturing
- F. Centrifuge/decant
- G. Protein purification
- H. Ultrafiltration
- I. Lyophilization

CES = Continuous Electrophoresis  
System



CES = CONTINUOUS ELECTROPHORESIS SYSTEM

Figure 2.2.1-1. Urokinase Process

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Following are the activities conducted in these steps.

- A. CES Sample Workup — This activity consists of withdrawing successive small aliquots from the onboard store of frozen mixed-cell kidney samples, thawing the samples, centrifuging the cells (in one or two steps), washing them, and then resuspending them in the CES buffer for introduction to the CES.

Although the CES can run essentially without interruption for hours to days separating the cells from the mixture, the cells are exposed to the CES buffer only the minimum time necessary for processing. Hence, only small portions of the raw sample are worked up at a time, say for 30-minute increments. To reduce manpower requirements, it may be possible to automate this step.

- B. CES Operation — The design and processing capacity of the CES have not yet been well defined. Two different approaches may be considered: (1) a continuous-particle electrophoresis system using a flowing buffer layer with the field applied edge-to-edge, and (2) a deflected-lamina electrophoresis with the field applied normal to the cell faces.

When a candidate separation technique has been selected for use in the zero-gravity environment, it will be first evaluated at 1 g on earth and then at 0 g in either the Spacelab or the Space Construction Base.

- C. Centrifuge/Wash — To reduce the exposure time of the kidney cells to the CES medium, the cells may be delivered from the CES into collector vessels containing protective additives. When a volume sufficient for a centrifuge run has accumulated, e.g., 2 to 3 liters, the cells are spun down, washed if necessary, resuspended, and introduced into the growth culture. An alternative is to omit any additive from the collector vessels, but to spin down the delivered cells more frequently and in smaller volumes, say 300 ml each, adding each to the growth medium as it accumulates.

- D. Growth Culture — The kidney cells will be introduced into specially designed culture chambers. Typical dimensions for commercial production are 61 cm x 61 cm x 61 cm (0.226 m<sup>3</sup> or 226 liters). These contain arrays of glass plates upon which the cells will multiply up to the point of confluence, i. e., until the available plate surface is completely covered. The cells do not multiply in free suspension. The culture medium is thermostatted and provided with gas exchange for supply of oxygen and removal of CO<sub>2</sub>.

The generation time (or time for doubling of cell count) is two days. The limit on multiplication is 30 generations, at which time the cells begin to transform, show altered chromosome structure, and lose their capacity to produce urokinase.

If the chambers used for growth are subsequently used for the production medium, they must be drained of growth medium and production medium substituted while the cells are in position on the plates.

The required volume capacity of the growth and production chamber (or array of chambers) will depend on the results of the optimization analysis in any case example.

- E. Production Culture — The cells do not significantly multiply during the production cycle. The medium is instead designed to maximize the urokinase production. The maximum useful life of the production culture is 40 days, at which time the accumulation of urokinase and/or other products results in a dropoff of urokinase production rate. The cells of the exhausted production batch cannot be used again. The supernatant is withdrawn for removal and purification of the urokinase. The culture chamber is cleaned for reuse.
- F. Centrifuge/Decant — The liquor from the production culture is centrifuged in consecutive batches, at relatively high speed if necessary, to remove residual cells, debris, and particulates of the culture broth from the supernatant.

- G. Protein Purification — For this step, a set of procedures must be established and operating conditions selected to isolate the protein of interest. This may include steps of concentration, precipitation by salt or solvent addition, adsorption, ion-exchange, or other types of chromatography and electrophoresis. Substantial manual handling may be involved, necessitating the development of methods of convenient transfer, mixing, and filtration of relatively large volumes of liquid — perhaps tens of liters at a time — in zero gravity. Relatively large solvent volumes may be required. An adequately sized work station must be provided, and a balance struck between overall equipment bulk on the one hand and excessive time consumed on the other hand in working with repeated small batches.

The specific steps involved in urokinase purification are not defined at this time. Standard devices for enzyme purification will be used, adapted as necessary for operation in space.

- H. Ultrafiltration — This operation desalts the purified protein solution and subjects it to concentration prior to lyophilization. The process is a form of reverse osmosis, the protein solution being applied under pressure to one side of a semipermeable membrane array, and a circulating wash solution applied to the other side. A representative apparatus applicable to the process is the Bio-Rad Model DC30 Hollow Fiber System for filtration.
- I. Lyophilization — In the final step in the process, the protein concentrate is freeze-dried in vials, and the vials are automatically capped. The product is then ready for low-temperature storage and return to earth. Lyophilizers of larger than laboratory scale carry a heavy burden of pumping and refrigeration equipment. A substantial saving in weight and power for a space-borne operation can be achieved if the external environment is used as a heat and vapor sink. A vacuum port for the lyophilizer should provide  $10^{-6}$  torr or less at the equipment interface.

Bioprocessing must be conducted in a sterile environment. Tests to determine and control quality and purity will be conducted during each step of the process.



### Mission Hardware

Because of proprietary factors and the need to isolate potentially hazardous materials, bioprocessing will require a dedicated module. The module will be approximately 12 m in length with a fully equipped weight of approximately 11,500 kg. As shown in the preliminary layout in Figure 2.2.1-2, the bioprocessing module will be divided into four sections — a crew preparation section, a decontamination section, a bioprocessing section, and an analytic services section. The last section will be a general-purpose laboratory where specimens are prepared for analysis, microscopic examinations made, materials stored, and chemical properties and biological activity determined. This module and its equipment complement have been sized for production of up to 2 kg of urokinase each 90 days. This production rate is adequate to satisfy clinical testing needs during the R&D phase, providing experimental doses of the enzyme for up to 1000 persons. The equipment requirements for the module, by section, are presented in Table 2.2.1-1.

It is assumed that three centrifuges will be used, one each for the sample workup, the centrifuge/wash, and the centrifuge/decant steps. The centrifuges will be standard, high-speed refrigerated types used in laboratories, modified for use in space. Facilities will be needed in the module for cryogenic storage of sensitive biological materials, large-scale storage of water which might be used in the process, and storage of containers or liners which are associated with the process, as well as for storage of solutions used in the process and waste products (such as exhausted chemicals, contaminated solutions, and waste cells).

#### 2.2.1.3 Activity Description

The technical objective of the urokinase production study is the development of a processing approach in space for biological materials with semi-continuous flow characteristics. The processing techniques and equipment utilized for urokinase should be applicable to many other materials, such as other enzymes, hormones, cells for transplantation, and hypophyseal cells.

The technical feasibility of improving bioprocessing by performing electrophoretic separation in space will have been partially demonstrated on a 7-day Spacelab mission. However, a 42-day period would be needed to carry out

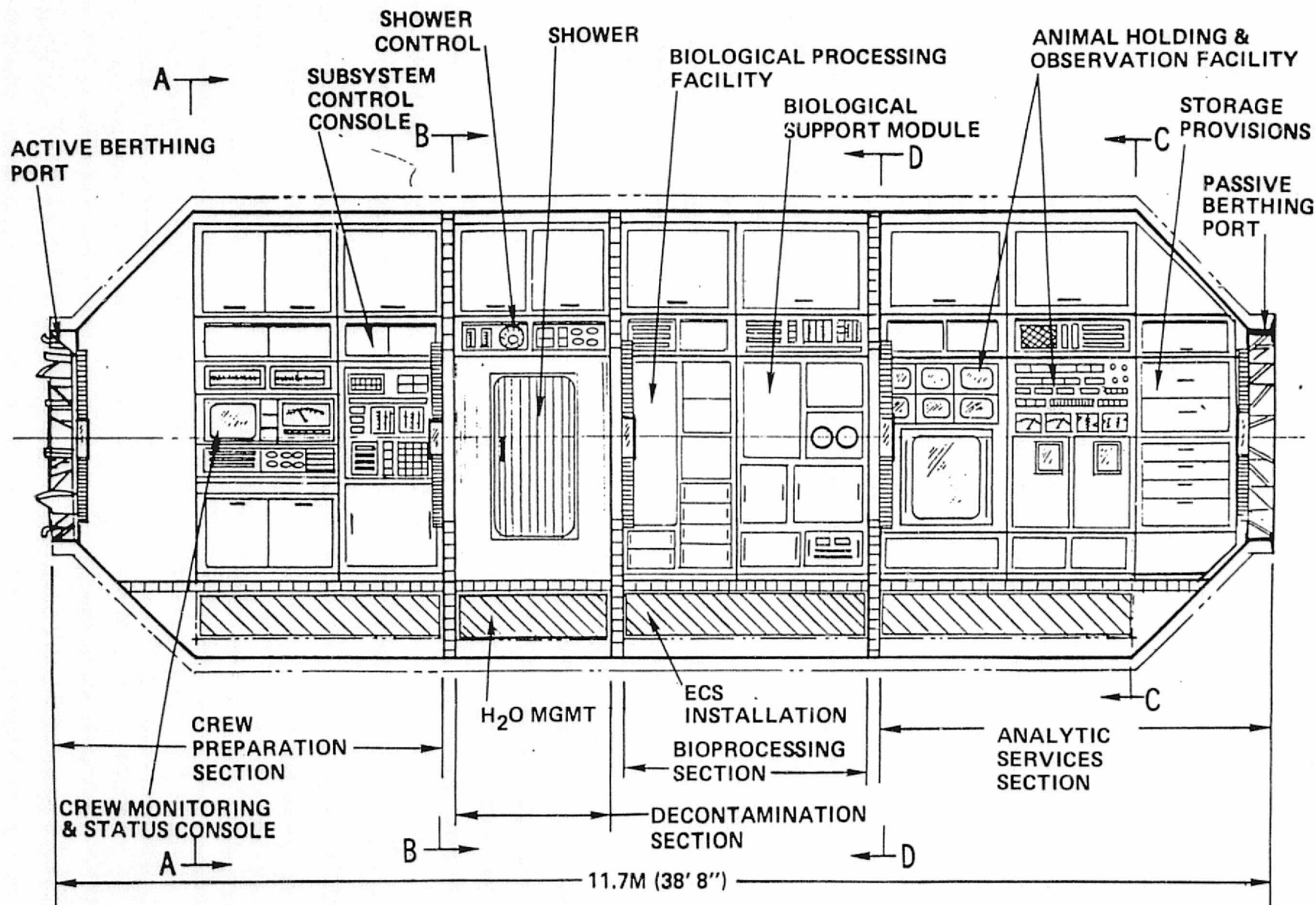


Figure 2.2.1-2. Bioprocessing Module—Urokinase (1 of 2)

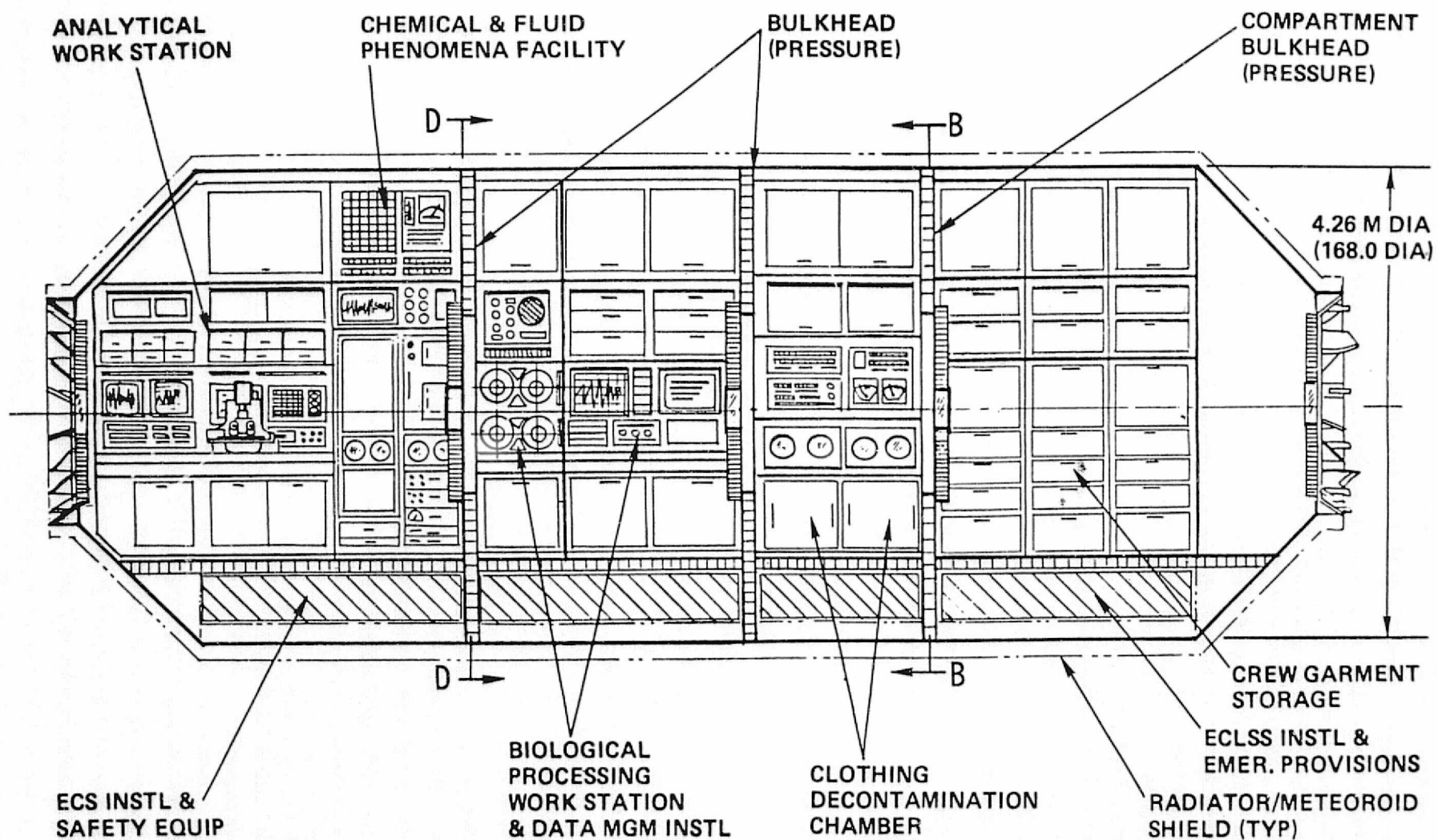


Figure 2.2.1-2. Bioprocessing Module-Urokinase (2 of 2)

Table 2.2.1-1 (Page 1 of 2)

## UROKINASE PROCESSING MODULE EQUIPMENT

Equipment	Step	Weight (kg)	Volume (m <sup>3</sup> )	Peak Power (kW)
BIOPROCESSING SECTION				
Continuous Electrophoresis System (CES-3)	B	620	0.66	4.50
Buffer Reconditioner	C	45	0.04	0.10
Centrifuge, Refrigerated (3)	C, F	825	1.95	6.00
Growth/Production Culture Chamber	D, E	155	0.61	0.70
Protein Purification	G	205	0.95	0.27
Ultrafiltration System	H	20	0.20	0.27
Lyophilizer	J	160	0.68	0.27
Low-Temperature Refrigerator (4°C)	For storage between steps	80	0.16	0.35
SUBTOTALS		2110	5.25	
ANALYTIC SERVICES SECTION				
Research Electrophoresis Unit		45.0	0.045	1.0
Preparative Electrophoresis Unit		10.0	0.010	0.10
Fraction Collection Unit		2.0	0.001	0.002
UV Absorption Scanner		2.5	0.008	0.10
UV Source		4.5	0.004	0.10
pH Monitor		6.0	0.012	0.05
Glove Box		15.0	0.030	0.05
Centrifuge		23.0	0.120	0.12
Mechanical Mixing Unit		2.0	0.001	0.10
Incubator		26.0	0.118	0.08
Lyophilization Unit		40.0	0.041	0.20
Dialysis Unit		4.5	0.027	0.20
Liquid Syringe Pump		7.5	0.001	0.02
Metering Pump		2.5	0.001	0.10
Particle Counter		25.0	0.150	0.10
Culture Tank		1.5	0.01	0.20
Microscope		15.0	0.03	0.10

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Table 2.2.1-1 (Page 2 of 2)  
UROKINASE PROCESSING MODULE EQUIPMENT

Equipment	Step	Weight (kg)	Volume (m <sup>3</sup> )	Peak Power (kW)
Refrigerated Storage Unit		57.0	0.277	1.0
Bio-freezing and Storage Unit		46.0	0.122	0.20
Buffer Supply Tank		2.0	0.002	
Electrolyte Supply Tank		2.0	0.002	
Waste Liquid Tank		1.0	0.004	
Gas Elimination Unit		2.0	0.005	0.05
Vacuum System		1.0	0.001	0.05
Fluid Cooling/Refrig. Unit		54.0	0.147	3.0
SUBTOTALS		397.0	1.169	
CREW PREPARATION SECTION				
Crew Monitoring and Status Console	}	TBD		
Subsystem Control Console				
Liquid/Gas Storage				
Gas Flow Meters				
Liquid Flow Meters				
Cryogenic Storage (-70°C)				
Containers and Liners				
Manual Transport Aids				
Controls/Displays				
Cleaning Equipment				
Recording Thermometers				
Pressure Instruments				
(Other TBD)				
DECONTAMINATION SECTION				
Shower and Controls	}	TBD		
Water Management				
Autoclaves (2)				
Dryers				
Cleaning Equipment				
(Other TBD)				

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all the steps in the process, so that Spacelab can be expected to provide only fragmentary data on the overall process efficiency. A major portion of the process development and optimization work will remain to be done on the SCB.

The bioprocessing module will be delivered by the Shuttle to the SCB and berthed. The SCB crew will verify that the module is properly attached to the base before the bioprocessing specialists enter the module and convert it to operational status. The specialists will unpack, check out, and set up all equipment, apparatus, and materials needed for the processing.

Before each processing cycle, solutions and samples will be transferred from storage and prepared for use. Efforts will be made to optimize the results by altering the major process variables in various combinations. The parameters to be changed include the pH factor and ionic strength of all solutions, the concentrations of the cells in the buffer media, the mobility of the leading, spacer, and terminating electrolytes, and the temperature, pressure, nutrient composition, and configuration of the growth culture habitat. Samples will be taken and analyzed to determine the effects of the altered parameters on the product.

Quality checks will be made throughout each processing cycle. For example, after the production culture growth step (Step E), the cells will be examined for ploidy (chromosome changes) and after the urokinase is purified (Step G), the activity of the batch of enzymes will be measured and recorded on a tag. During recycling of the treated water used for solutions, samples of the water will be injected into rabbits to ensure that it is free of pyrogens, a fever-producing substance. When the final step, lyophilization, has been completed, the product will be packed together with all processing data for a return shipment on the Shuttle to Earth.

A sample schedule for processing of urokinase is given in Figure 2.2.1-3.

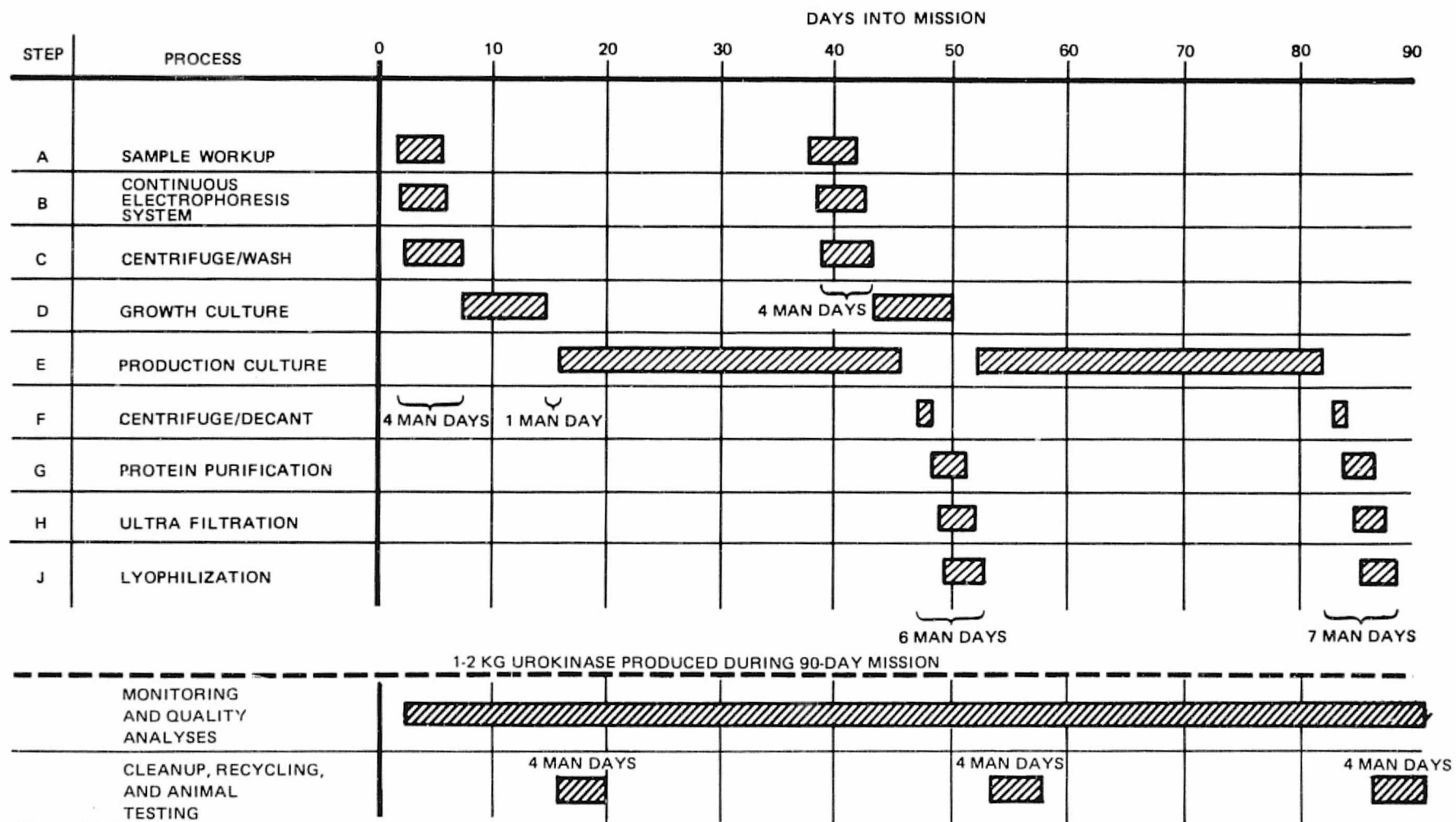


Figure 2.2.1-3. Processing Schedule Case Example

#### 2.2.1.4 Space Construction Base Requirements

##### Power

The power profile to be provided by the SCB is shown in Figure 2.2.1-4.

##### Environmental Control

Temperature, humidity, pressure, cleanliness control, and heat rejection, plus CO<sub>2</sub> removal and oxygen replenishment will be provided by mission hardware.

##### Acceleration and Noise Control

The acoustic level must be maintained at less than 70 db and the acceleration must be maintained at less than  $10^{-3}$  g during cell separation (Step B). During cell growth (Step D), acceleration must be limited to (TBD).

##### Waste Management

Waste storage, control, and transfer will be accomplished by mission hardware. Effluent types and quantities will be limited to:

<u>Effluent</u>	<u>Quantity (kg/day)</u>
TBD	TBD

##### Data Management/Communications

Requirements on the SCB in addition to a secure voice link to ground will be limited to a TV link to ground with ground-controllable scan and zoom lens on the camera, plus a digital link capable of transmitting 10 kb of process and test data to the ground each day. (Ground control will be provided to comply with regulations of the Food and Drug Administration.)

##### Personnel

Two bioscientists and a technician will be required for the processing. Manpower use during processing is shown in Figure 2.2.1-3. In the case illustrated, 22 man-days will be needed for processing each 90 days. The operator time is utilized mainly in (1) sample workup and CES operation prior to the culturing steps, (2) the period where the two cycles overlap, involving both preculturing and postculturing steps, and (3) the final postculturing operations before the end of the mission period. Automation in sample workup and continuous particle electrophoresis operation may conceivably



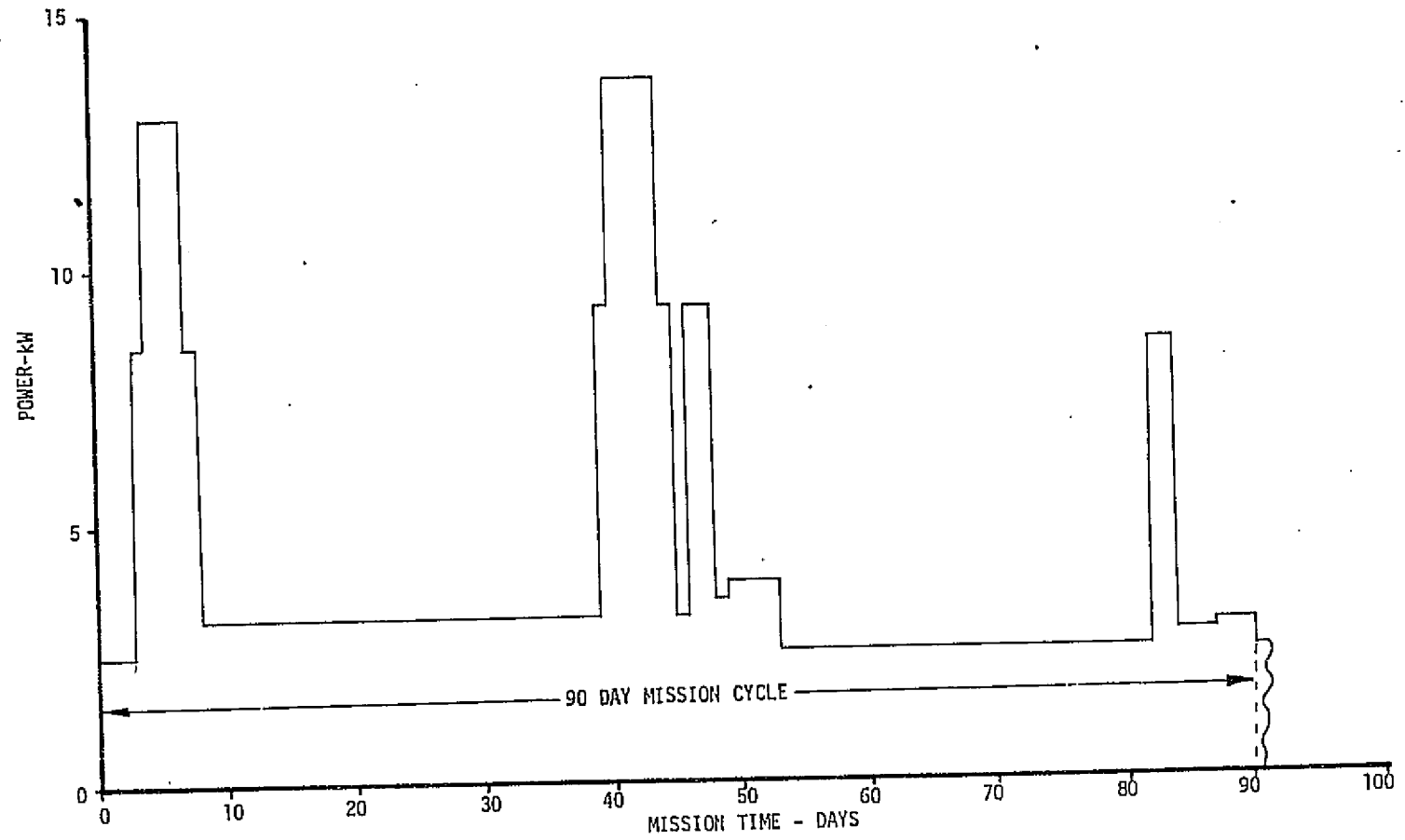


Figure 2.2.1-4. Biproprocessing Power Profile

reduce operator time by a total of 4 man-days. The postculturing steps, on the other hand, are less amenable to automation.

### Safety

Potentially hazardous conditions and materials associated with urokinase processing are:

<u>Conditions</u>	<u>Materials</u>
Spills	Flammable fluids
Leaks	Corrosive fluids
Biocontamination	Toxins
	Radioisotopes
	Biologicals

Measures to preclude or limit hazards to personnel and equipment will include:

- A. An independent environmental control and life support subsystem for the urokinase processing module to prevent transmittal of contaminants to the SCB proper.
- B. Decontamination of personnel exposed to the bioprocess. This will be accomplished by showering and changing to sterile clothing.  
(Other TBD)

### Logistics

Resupply will be accomplished as an adjunct to Shuttle flights whose primary purpose is the transport of various mission hardware. Assuming that these flights occur on approximately 90 day centers, about 270 kg of supplies and consumables and 150 kg of equipment and spares will be required by the processing module. The combined volume will be less than 1 m<sup>3</sup>. One to two kilograms of lyophilized urokinase will be returned.

#### 2.2.2 Ultrapure Glasses — Fiber-Optic Preforms

##### 2.2.2.1 Mission Overview

The overall objective of the glass case study is to develop mission requirements that are both reasonable and representative of glass product production. Fiber-optic glass (fused silica) is produced using a batch glass process, therefore is representative of other glass products which potentially could

benefit from space processing (e.g., high-CaO-content lasing glass). The choice of fiber-optic preform production for the ultrapure glass study resulted from the on-going interest in the use of fiber optics for communication systems.

The fiber-optic preforms will be produced in a processing module attached to the Space Construction Base (SCB). The preforms (Figure 2.2.2-1) consist of a pure fused-silica core with a borosilicate glass cladding. In the low-gravity environment of space, glass can be melted, shaped, annealed, and clad while suspended in a contactless state in a furnace. Contamination can therefore be held to a minimum. The low-gravity environment of the processing module therefore is expected to allow production of preforms of exceptional purity — e.g., approaching the minimum theoretical light attenuation of 0.5 db/km for fiber-optic transmission.

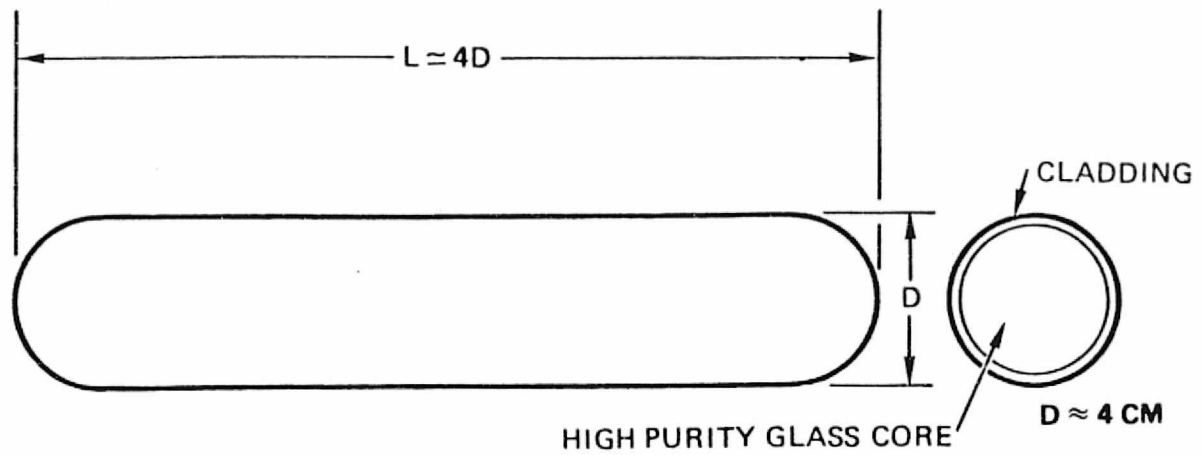
The cylindrical shape of the preform is applicable to many glass products. For example, glass lasing rods and components of electro-optical devices could be candidates for space production since their basic form would be cylindrical. Thus the mission hardware, discussed later in this section, is not unique to the production of fiber-optic preforms alone.

#### 2.2.2.2 Process and Mission Hardware Descriptions

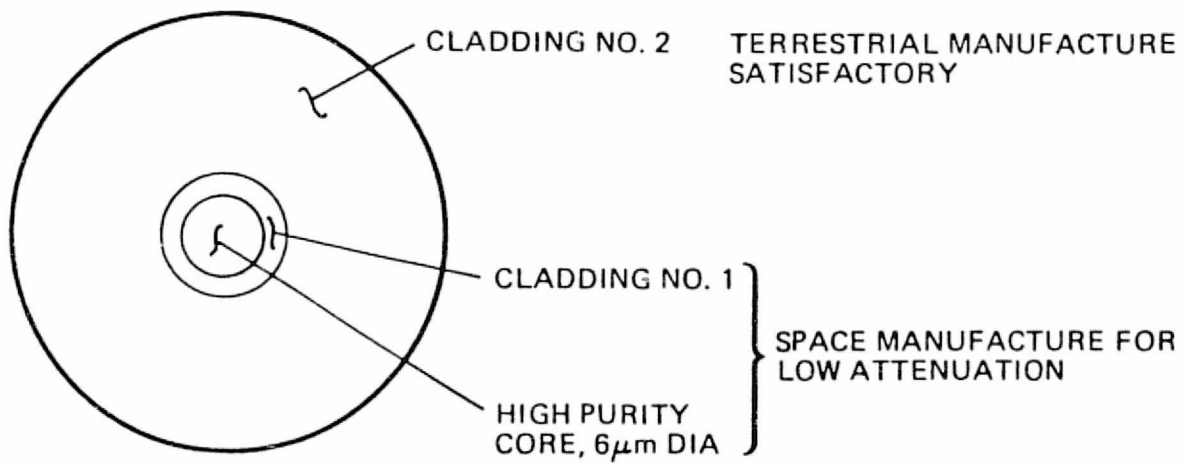
##### Technical Objectives

The main technical objective of the case study mission is production of fused silica glass of such purity that the minimum theoretical light attenuation of 0.5 db/km may be approached when the glass is used for fiber-optic transmission systems. Fiber-optic glass currently in use exhibits a light attenuation of approximately 2 db/km. The 0.5 db/km attenuation limit is due to molecular Rayleigh scattering in completely pure silica glasses. The remainder of the losses are thought to be caused by impurities, including those resulting from contamination by crucibles.

Five-db/km fiber-optic communication systems are felt to be competitive with coaxial and microwave systems. Nonetheless, studies show that a reduction in attenuation from 2 to 1 db/km would justify an increase in fiber-optic cost in excess of \$50,000/kg.



#### Space Produced Fiber-Optic Preform



#### Final Drawn Fiber

Figure 2.2.2-1. Fiber-Optic Characteristics

The objective of the early SCB activity concerning processing of ultrapure glasses in low-gravity environment is to demonstrate:

- A. Melting of large boules in a containerless mode to obtain homogeneous melts.
- B. Rapid cooling of large glass melts.
- C. Shaping of glassy material with desired accuracy in a containerless mode.
- D. Application of controlled coating thickness to glass preforms.
- E. General glass handling techniques to preserve pristine surfaces.

#### Process

SCB production of fiber-optic preforms is preceded by constituent material production on earth. The predetermined glass-forming constituents are mixed and dry-pressed into easily handled slugs at a terrestrial facility. These slugs, along with cladding material, are then transported to the SCB by Shuttle Orbiter.

To produce the desired high-purity glass preforms, five processing activities (Steps A through E of Figure 2.2.2-2) will be conducted in the low-gravity environment of the SCB-based fiber-optic preform processing module.

During Step A, the slugs will be melted in a contactless furnace at 1800C, then quenched to form glass. The furnace must be capable of maintaining the glass melt in a stable position without furnace contact to prevent contaminants from being introduced into the melt. Various methods are available for providing contactless positioning in a furnace. Since the melting process will probably require an oxidizing environment, some version of acoustic positioning seems preferable.

Equipment required for glass formation, in addition to the contactless furnace, includes melt-quenching apparatus, a vacuum (gas purging) system, gas tanks (atmosphere supply), glass-handling apparatus, and coolant.

The shaping of the spheroid-shaped glass into a cylindrical preform (Step B) must also be accomplished without contact in order to avoid contaminating

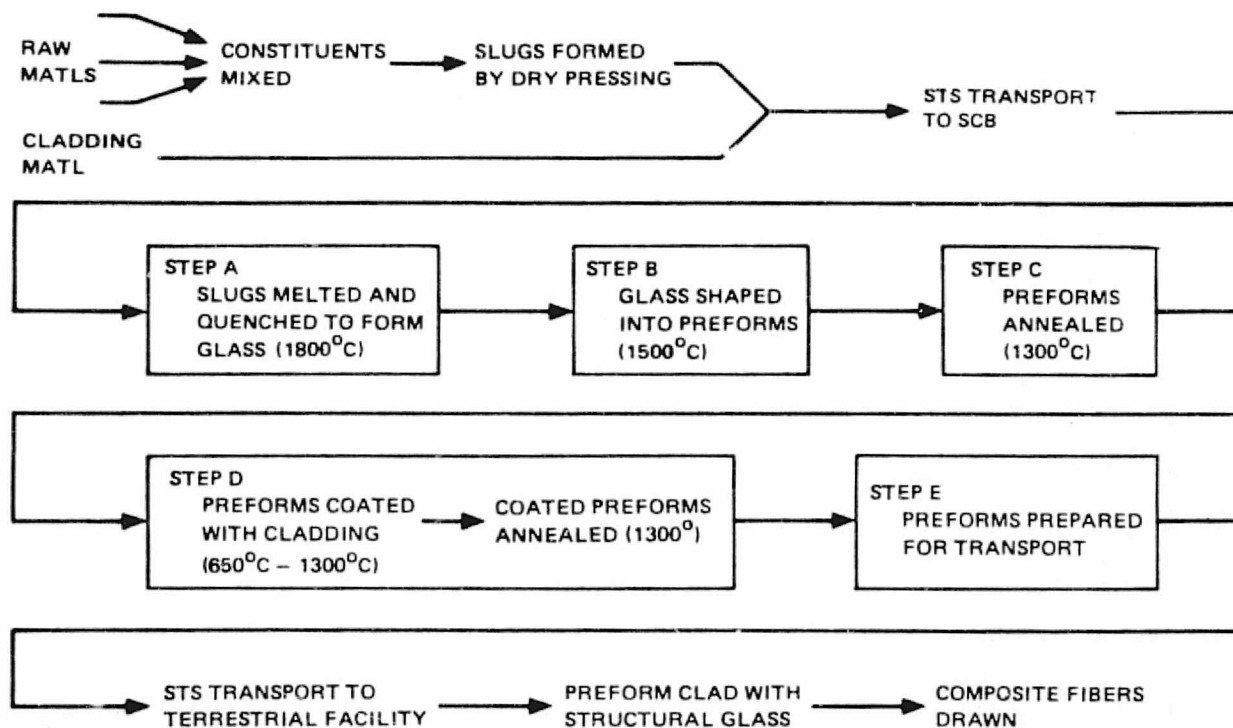


Figure 2.2.2-2. Fiber-Optic Preform Production

the pristine surface of the preform prior to cladding it with lower refractive index glass. The shaping could be done in the same furnace that is used for glass formation, but use of a separate furnace with shaping capabilities is recommended so the formation process would not be held up.

Step B equipment would include a tube-type furnace containing shaping apparatus, preform handling apparatus, and atmosphere (gas tank) and coolant supplies.

Once shaped, the preform must be annealed (Step C) to relieve the residual strains induced in the shaping process. Annealing could be done in the shaping furnace following shaping, in a separate annealing furnace, or in the cladding furnace. However, the use of different furnaces for different processing activities is recommended because the activities take different amounts of time to accomplish, and the use of the same furnace for different kinds of processing could result in inefficient rates of production. At present, the superior combination of furnaces appears to be:

- A. Contactless melting furnace for glass production.
- B. Contactless shaping furnaces for preform shaping.
- C. Annealing/cladding furnaces to support those activities.

A tube-type cladding furnace, similar in size to that used in the shaping process, seems most attractive for annealing and cladding the preform (Steps C and D). The furnace would be equipped with a preform-rotation device and a cladding material holder/heater/translating drive-screw device.

Since the annealing process occurs at a temperature 300 to 500° below the melt point of 1800°C, the preform can be supported during the process without contaminating the glass. Thus, preforms probably could best be annealed in the cladding furnace before they are exposed to the cladding material. Consequently, no requirements exist for annealing equipment other than that supporting the cladding operation (e. g., the cladding heater translator.

Preforms could be clad in several ways. One would be to heat the cladding material above its flow point locally in an enclosure and bring it into contact with the glass preform by moving the clad melt slowly past the preform.

Maintaining the enclosure at a temperature above the cladding softening point but below its melt temperature would allow a coating of cladding material to be "wiped" onto the glass preform. This material would be a borosilicate glass that has a refraction index lower than that of fused silica. The cladded preform would then be annealed at 1300°C in the same furnace to relieve any residual strains resulting from the cladding operation.

The preforms will be prepared for shipment (Step E) by packaging them in individual protective containers, then packing the packages in shipping containers for earth transport via the STS.

#### Mission Hardware

Table 2.2.2-1 defines the equipment required for fiber-optic preform production along with attendant weight, volume, and power requirements. The weight and volume associated with supporting subsystems and structures are not included.

The weights of the furnaces are based on typical furnace weights of 1280 kg/m<sup>3</sup>. The furnace volume is a direct function of the mass to be melted in the furnace; for example, a furnace melting a 1-kg mass would have an outside dimension of 70 cm and would occupy a volume of approximately 0.02 m<sup>3</sup>. The preform processing equipment requires a total volume of 4.0 m<sup>3</sup>; this is included in the work volume of 38.0 m<sup>3</sup> contained in the module processing section. The equipment would weigh 1725 kg not including the weight of structural supporting hardware. The mission hardware will be designed, modified, or packaged to withstand the STS launch environment.

#### Processing Module

The processing module, both sides of which are shown in Figure 2.2.2-3, is 11.7 m long by 4.26 m in diameter and weighs 14,500 kg. Module volume is 175 m<sup>3</sup> with equipment occupying 112 m<sup>3</sup> and crew working area 63 m<sup>3</sup>. The processing module will condition SCB-provided power into 115 VAC, 60 Hz, single phase and 28 VDC, regulated, as required.



Table 2.2.2-1  
FIBER-OPTIC PREFORM PRODUCTION EQUIPMENT REQUIREMENTS

Equipment	Volume (m <sup>3</sup> )	Weight (kg)	Power (kW) Peak/Sustaining
Processing Enclosures			
Contactless melting furnace <sup>(1)</sup>	0.26	345	12.0/5.2
Contactless shaping furnace	0.10	160	6.0/3.0
Annealing/cladding furnaces	0.20	295	8.5/5.1
Process Control			
Pyrometers (2)	0.054	18	0.10/0.10
Thermocouples	N/A	Negligible	N/A
Pressure controllers	0.061	7	0.05/0.05
Microprocessor system	0.041	37	0.30/0.30
Atmosphere Control			
Gas supply and manifold	1.50	90	0.30/0.30
Residual gas analyzer	0.061	34	0.25/0.25
Vacuum system	0.020	45	0.50/0.30
Particulate filter system	0.008	5	N/A
Inspection			
Laser optical scattering system	0.145	102	1.2/0.25
Shape comparator	0.027	35	0.20/0.20
Binocular microscope	0.054	23	0.15/0.15
Thickness measurement system	0.027	35	0.25/0.25
Manipulators			
Glass handling	0.027	15	0.1/0.1
Rotation drive assembly	0.027	25	0.15/0.15
Cladding heater translator	0.013	7	0.1/0.1
Material Storage			
Raw material	0.010	100	N/A
Product	0.010	100	N/A
Packaging/containers	0.025	15	N/A
Totals	4.0 <sup>(2)</sup>	1725 <sup>(3)</sup>	N/A

(1) Includes contactless quenching apparatus

(2) Includes 45% packing density factor

(3) Includes 10% miscellaneous allowance but does not include process control and monitoring console, structural support hardware, cabinets, etc.

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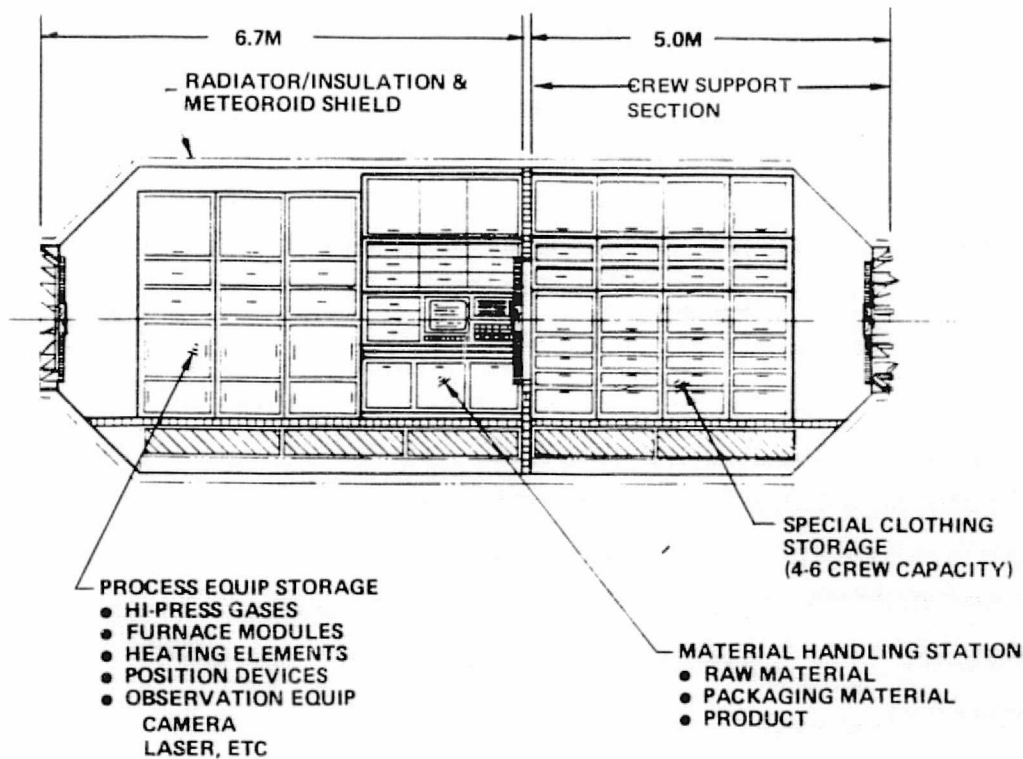
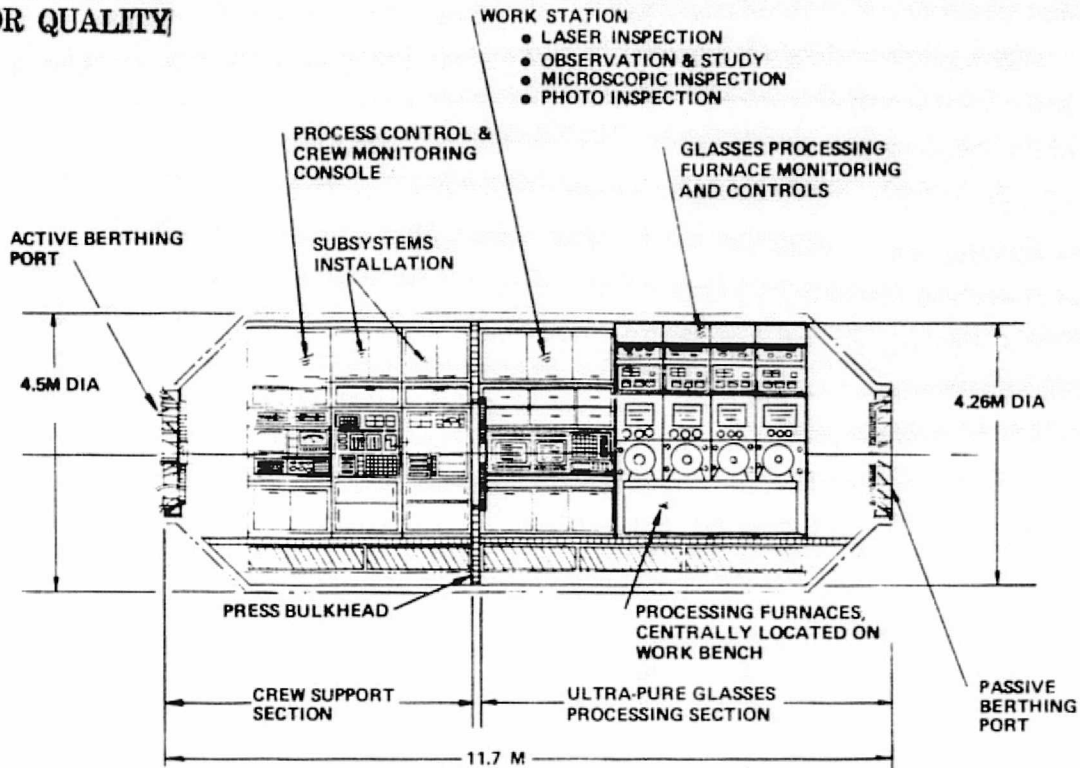


Figure 2.2.2-3. Fiber-Optic Preform Processing Module

The module consists of two compartments, one for processing and one for crew support and centralized monitoring control of the processing functions. Foldout equipment bays provide back-of-rack maintenance, servicing, and equipment changeout. Full access to furnaces provides for furnace equipment adjustments. The pressure bulkhead between the module sections provides for evacuating personnel in the event an emergency occurs in the processing section of the module.

The glass inspection and characterization station in the processing section of the module contains the equipment required (Table 2.2.2-2) to inspect and characterize the products of the various preform production steps.

#### 2.2.2.3 Activity and Test Description

The schedule of Figure 2.2.2-4 shows the preform production rate for the first 90 hours of a 90-day mission. The first preform should be produced and packaged approximately a day and a half after glass forming operations have commenced. Once production is underway, one preform should be produced about every 8-1/4 hours.

The preforms, weighing 380 grams each, will be produced at a rate of 260 during each 90-day period between Orbiter resupply missions. The Orbiter will transport approximately 100 kg of glass slugs to the SCB each trip to support this production rate, then carry approximately 100 kg of finished preforms back to earth. This is felt to be the most economical combination of preform production rate and Orbiter shipment size.

The same containers will be used to ship the glass slugs to orbit and the completed preforms to earth. The preforms will be packaged and stored at a work station aboard the processing module.

On return of the preforms to earth, they will be drawn into rods, clad for strength, and then drawn into fiber for use in fiber-optic transmission systems.

Table 2. 2. 2-2  
GLASS CHARACTERIZATION EQUIPMENT REQUIREMENTS

Equipment	Volume (m <sup>3</sup> )	Weight (kg)	Power (kW) Peak/Sustaining
Processing Enclosures			
Contactless melting furnace	0.190	65	3.0/2.0
Thermal oven	0.027	25	1.0/0.50
Glove box	0.027	25	N/A
Preparation Apparatus			
Slip casting unit	0.001	2	N/A
Rheological unit	0.005	5	0.05/0.05
pH monitor	0.012	15	0.05/0.05
Grinding/polishing unit	0.082	110	0.35/0.20
Mechanical mixing unit	0.001	3	0.05/0.10
Mass measurement unit	0.001	5	0.10/0.20
Process Control			
Pyrometers	0.027	9	0.05/0.05
Pressure controllers	0.061	7	0.05/0.05
Thermocouples	N/A	Negligible	N/A
Microprocessor system	0.041	31	0.30/0.30
Residual gas analyzer	0.061	34	0.25/0.25
Gas supply system	0.5	30	0.1/0.1
SCR power controllers	0.060	15	0.2/0.2
Particulate filter system	0.005	5	N/A
Vacuum system	0.020	45	0.5/0.3
Analytical Instrumentation			
IR spectrophotometer	0.041	45	0.2/0.2
X-ray fluorometer unit	0.045	42	0.2/0.2
Refractometer-spectrometer	0.035	41	0.1/0.1
UV visual spectrophotometer	0.038	45	0.2/0.2
Mass spectrometer	0.035	35	0.3/0.3
Binocular microscope (100x)	0.026	23	0.1/0.1
Differential thermal analyzer	0.030	25	0.25/0.25
TOTALS	1.95 <sup>(2)</sup>	750 <sup>(3)</sup>	

(1) Includes contactless quenching and shaping apparatus

(2) Includes 45% packing density factor

(3) Includes 10% miscellaneous allowance but does not include structural supporting hardware.

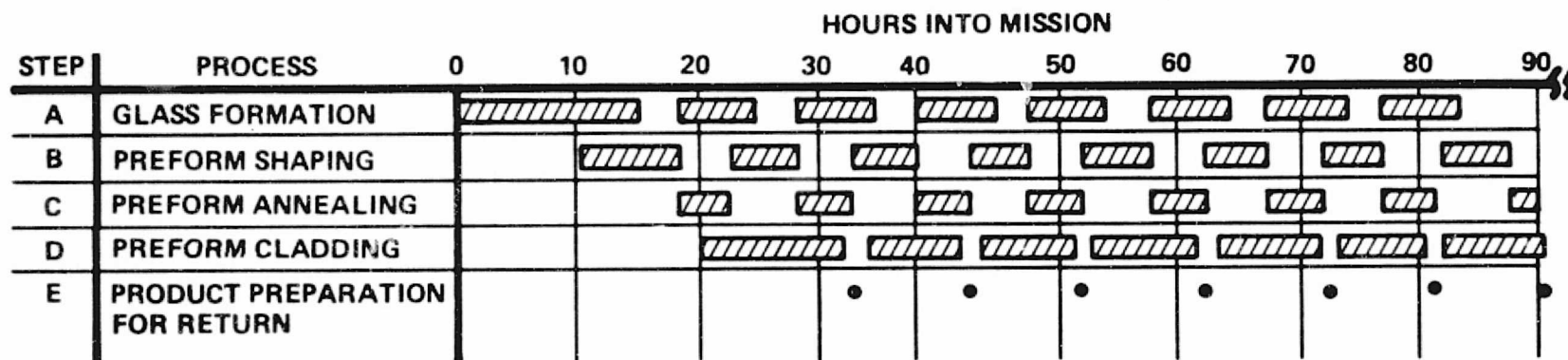


Figure 2.2.2-4. Processing Schedule

### Safety

Requirements exist for guarding against three hazards inherent in glass processing: The inadvertent release of high temperature material or toxic waste gases, or an explosion caused by pressurized oxygen. Glass materials will be heated to temperatures approaching 2000° C. Beryllium oxide and fluoride will be used to purge the furnaces. The furnaces will be oxygenized under very high pressures.

Standard industrial safety designs adequate to eliminate these hazards have been incorporated in the affected processing module equipment and their operation. Occupational Safety and Health Act (OSHA) standards will be met.

### Test Requirements

The test requirements associated with each of the technical objectives can differ depending on the product goals which the material is to satisfy. However, almost all batch glass material will require postmelt and quench tests, postshaping tests, postannealing tests, and postcladding tests. The tests are typical of those conducted during the development of a new glass which is to be used for optical purposes.

Postmelt and quench tests are required to determine if the unit process operations were satisfactory and if the desired properties were achieved in the glass formed. Such tests would include:

- A. Examination for blisters or seeds by magnification and/or light scattering.
- B. Examination for devitrification and cord formation.
- C. Examination for surface checks.
- D. Tests for desired optical and/or mechanical properties. In the fiber-optic example, such parameters as refractive index and dispersion coefficients would be determined.

Postshaping tests are required to determine the adequacy of the shaping process. The product will be examined for dimensional characteristics against the requirements and for surface blemishes, laps, or checks.

The shaped glass preforms will be subjected to birefringence and extended-duration refractive index tests to assess the relative degree of annealing. These postannealing tests will help establish the required annealing schedule for the glass.

The cladding will be examined for coating continuity, coating thickness uniformity, and refractive index. The postcladding tests will be conducted to determine whether or not cladding or coating process parameters are appropriate.

Preform inspection and test will be conducted prior to cladding and prior to preparation for shipment.

The furnace parameters (pressure, temperature, gas composition) will be recorded for use in troubleshooting operational modes. The data will be erased if inspection shows no product abnormalities. Data will be taken every five minutes when a furnace is operational.

#### 2.2.2.4 Space Construction Base Requirements

The SCB support required to produce fiber-optic preforms in the process module is described in this section. SCB requirements were derived from such preform production parameters as equipment, power, volume, weight, habitability, data and communications, and safety.

##### Power

Requirements for SCB power to support preform process module operations range from approximately 12 kW between process operations to approximately 30 kW in an all-powered-up situation when the glass-making furnace is operating at the same time nonprocessing activities are taking place.

The glass processing power profile for the first 54 hours of a 90-day mission is shown in Figure 2.2.2.-5. The first 36 hours are spent in warming up the furnaces and producing a practice preform. From that point, preforms are produced at a rate of 1 about every 8 1/4 hours. Peak power demand for processing activities alone is about 26 kW for approximately 1 hour every 8 1/2 hours.

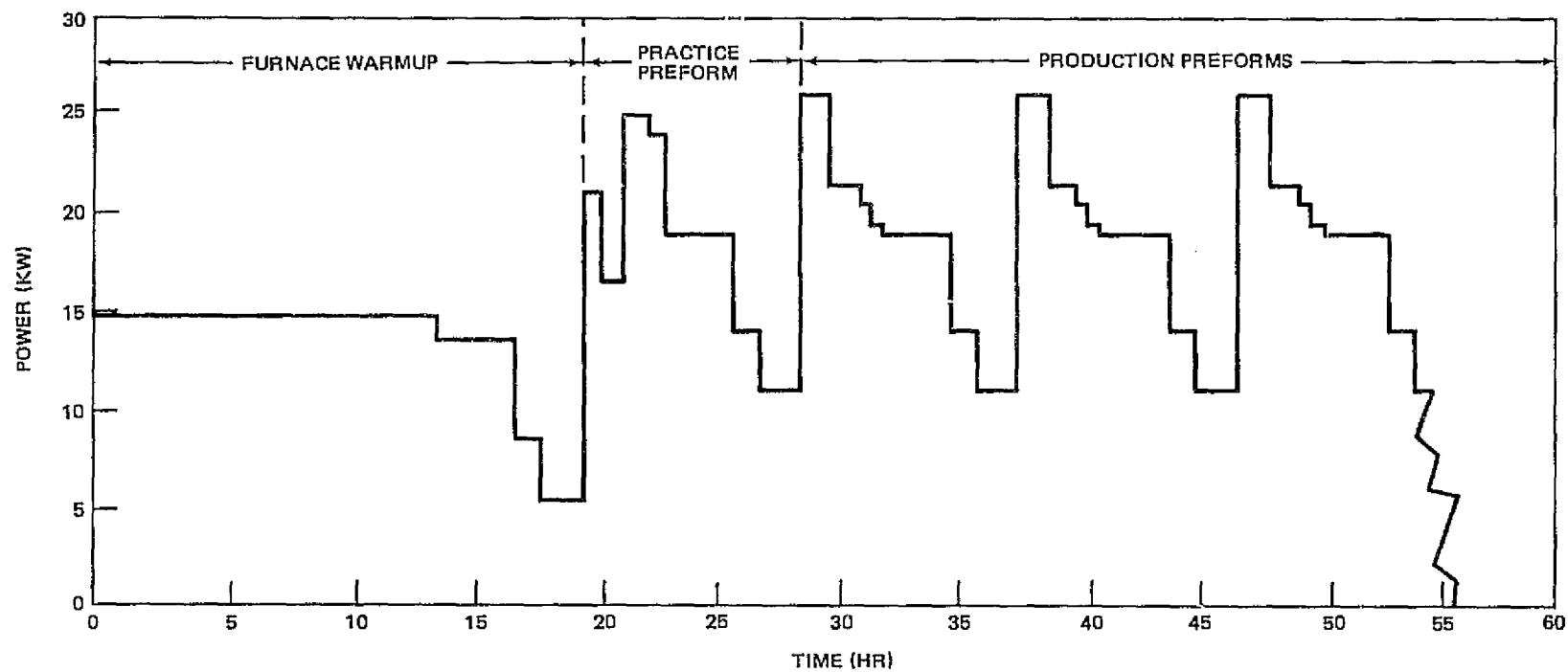


Figure 2.2.2-5. Fiber-Optic Preform Process Power Profile



The processing operations are considered to include the following support activities: process control, data formatting, ancillary unit processing, and inspection and analysis. A total of 2.5 kW is allocated for these activities; this is considered to be a constant load and is included in the power loads of Figure 2.2.2.-5. Voltage parameters are 230 VAC, 400 Hz, and single or three phase.

The profile represents a sequencing of the individual apparatus power in a mode which results in the maximum instantaneous power requirement. The peak power requirements could be reduced 8 to 10 kW by maintaining the glass formation and annealing furnaces "at temperature" after the initial warmup. However, this would raise the average power requirement to (TBD) kW.

Furnace power consumption is a direct function of the mass to be melted in the furnace (furnace charge); for example, a furnace melting a 1-kg mass would have an equilibrium power consumption of 8 kW.

#### Environmental Control

Temperature, humidity, and cleanliness requirements for the processing module are the same as those for SCB shirtsleeve activity. Furnace cooling will be provided by the SCB thermal control fluid loop. The required heat rejection is 26 kW<sub>T</sub>.

#### Acceleration

During the glass formation and shaping processes, the local gravity level must be maintained less than  $10^{-3}$  g.

#### Waste Management

Waste management will be accomplished using mission hardware. Effluent types and quantities of waste will include various gases with toxic constituents in the parts-per-million range. Types of gases are oxygen and nitrogen, and perhaps argon.

### Data Management and Communications

No real-time communication with terrestrial stations will be required as a normal practice. However, a secure voice link with the ground must be available so process module crew members can privately discuss proprietary matters concerning process development and operations. The SCB ground communications network will be used for these confidential discussions.

Certain safety-critical functions will require caution and warning (C&W) capability. A master C&W system aboard the SCB will support this requirement.

The module will have its own computerized data recording system.

### Personnel

Several operations can occur simultaneously in the fiber-optic preform production process. Operation of the process module by two crew members during each 12-hour shift therefore is recommended. Three men working staggered shifts was found to be unsatisfactory. On the other hand, there is insufficient activity to support three operators in any given 12-hour shift.

The optimum arrangement will be a full-time engineer and a full-time glass technologist for each 12-hour shift in a 2-shift day. At peak work loads, these crewmen could be supported by an SCB crewman who had undergone sufficient training to accomplish certain preform processing tasks.

### Logistics

The preforms will be packaged individually in protective containers. The individual containers then will be aggregated into shipment containers for transport vis STS. The shipment containers will weigh a total of approximately 15 kg and will require approximately  $0.1 \text{ m}^3$  of storage volume aboard the processing module. The slugs and preforms will use the same shipping containers. The production of preforms in economical quantities will require the transportation of approximately 100 kg of glass slugs to the SCB each 90 days and the return of a shipment of finished preforms weighing about the same.

## 2.2.3 Shaped Crystals - Silicon Ribbon

### 2.2.3.1 Mission Overview

Silicon ribbon has been selected for this case study, which will begin in 1984, because it is representative of a major class of crystals that could be grown and shaped in space. The advantage of space processing is that containerless melting in microgravity can produce a high purity and homogenous product in significantly higher yields than is possible on Earth. In later solar cell applications, the space processing will also provide major increases in efficiency. However, the process must be made cost-effective to enable space-made silicon ribbon to compete in the integrated circuit semiconductor market.

Starting in 1986, methods and equipment will be developed for processing silicon ribbon into solar cells, which will be assembled onto a solar power satellite that converts solar energy directly into electricity. The solar cell processing is a prerequisite to the development of the solar power satellite.

The case study also provides for the development of space processes for shaping other types of crystals.

### 2.2.3.2 Process and Mission Hardware Descriptions

The space processing, in essence, will transform polycrystalline silicon in the form of rods shipped from Earth into single-crystal silicon in ribbon form which is suitable for use as semiconductors. The processing will be done in a module dedicated to shaped crystal production. The module, shown in Figure 2.2.3-1, will be 15 m long and 4.26 m in diameter, with the space divided into two compartments, one for a work station and the other for office and storage use. The module will feature foldout equipment bays and have an access tunnel to the SCB. The module will weigh 14,500 kg and have a volume of 222 m<sup>3</sup>; 142 m<sup>3</sup> for equipment and the remaining 80 m<sup>3</sup> for work area.

The work station will have three types of equipment; (1) the processing apparatus; (2) control and data instrumentation, and (3) general-purpose laboratory instruments and devices for material analyses by the work crew.

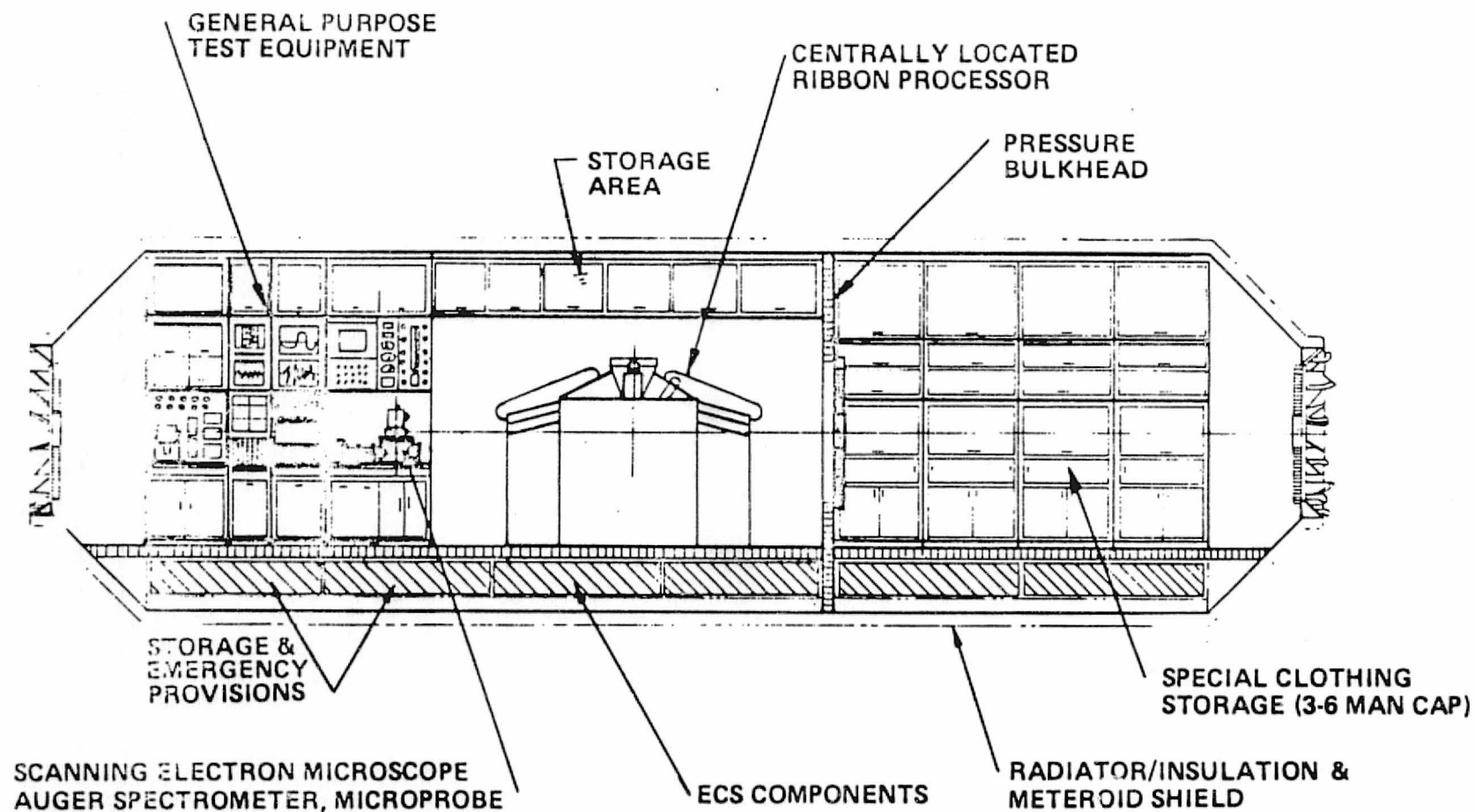


Figure 2.2.3-1. Shaped-Crystal Processing Module (Sheet 1 of 2)

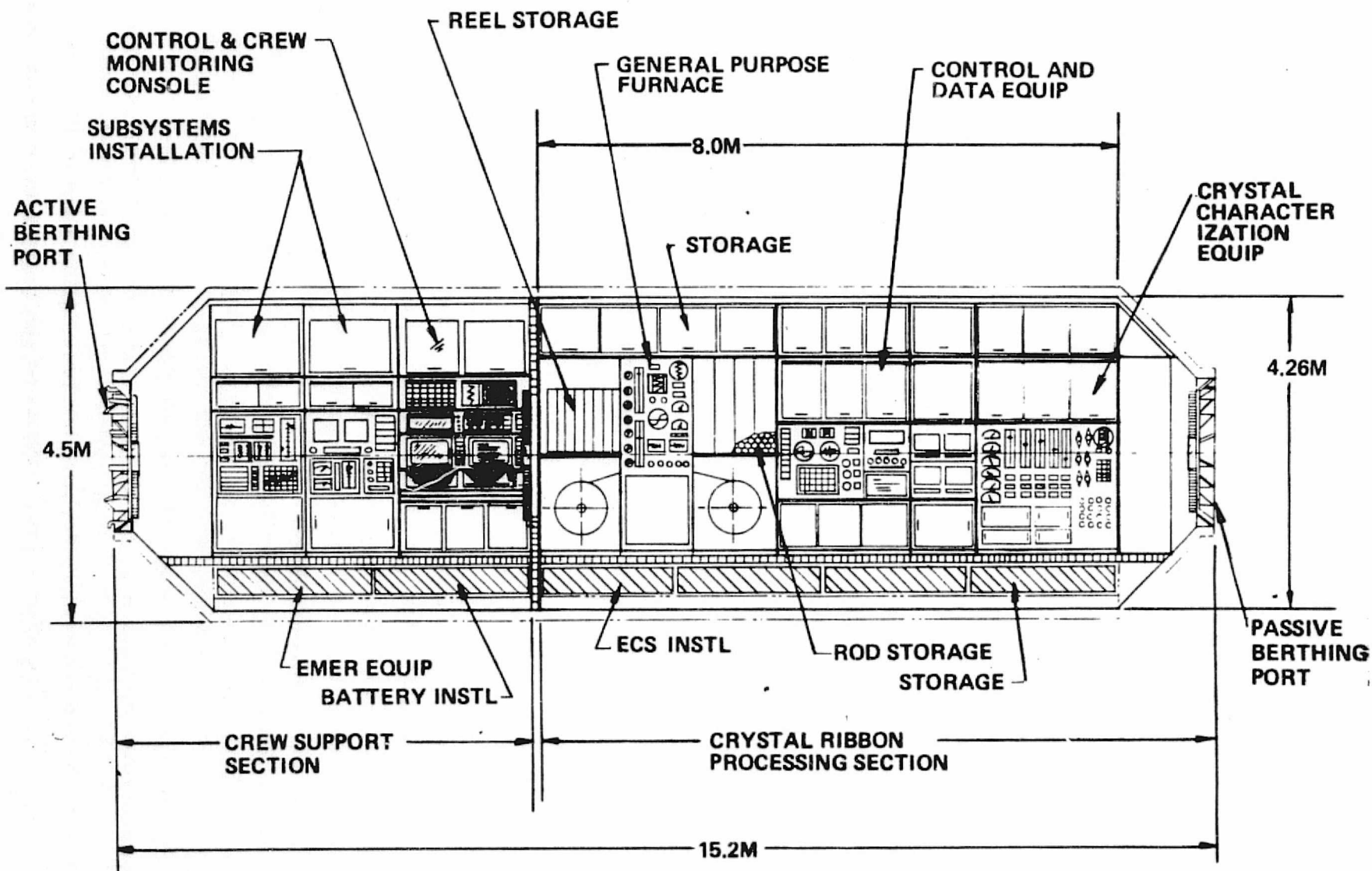


Figure 2.2.3-1. Shaped-Crystal Processing Module (Sheet 2 of 2)

Production will be fully automated and continuous to produce 190 cm/hr of silicon ribbon, or more than 300 m of the shaped crystal every week.

The automated processing will begin when two polycrystalline rods, 60 to 65 cm long and about 5 cm in diameter, are fed simultaneously from different directions on a roller-type mechanism into a furnace, where heat will be applied at their confluence to form a melt. The feed rate of the rods will be 1.3 cm per hour. The furnace atmosphere will be a noble gas such as argon to prevent undesired reactions. The molten material will be held in space by proper geometric location of the rods and the pulling/growing mechanism, thus levitating the melt to prevent contact with the furnace walls. At the start of the crystal pulling, a single silicon seed crystal will be introduced to begin the solidification process. The growing crystal pulled from the melt and passed through an electromagnetic shaping device will take the form of a rectangular ribbon, 7.6 cm wide and 0.4 mm thick, as it solidifies.

The ribbon will then be wound onto a storage reel. A cutter will periodically extract a piece of ribbon for automated quality control checks before the material moves onto the reel. If the quality checks should fail, the production apparatus will automatically stop. Highlights of the fabrication process are shown in Figure 2.2.3-2.

Temperatures will change at different stages of processing. The rods will be heated as they are fed into the melt, where they will be subject to a peak furnace temperature of over  $1400^{\circ}\text{C}$ . As the silicon moves through the shaper, it will be cooled so that it will solidify, and it will be further cooled in a controlled fashion as it is wound on the reel.

The computer-controlled apparatus will be equipped with instruments and sensors to measure the material thickness, the rate of feed, the rate of extraction, the shaping current, and the temperatures at various stages in the process.

For production of high quality silicon ribbon solar cells, the process will be modified. Boron-doped polycrystalline feed rods will be used to form and maintain the melt. The seed will be introduced and the crystal drawn through

Steps

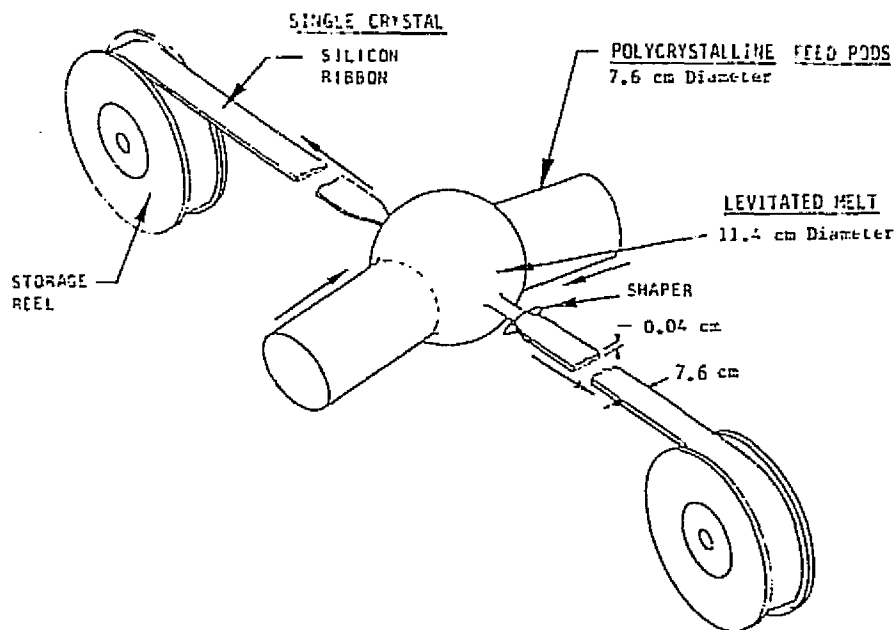


Figure 2.2.3-2. Ribbon From Melt Growth in Space Process

the shaping die, forming a boron-doped 0.1 mm x 7.6 cm ribbon. While still hot (~600° to 700°C), the ribbon will be drawn through a phosphene gas chamber where phosphorus will be diffused to a depth of approximately 0.1  $\mu$ m into the top surface, forming a solar cell diode. This continuous diode will then be passed through a metallization chamber where a mask will be applied to the top surface and aluminum vacuum-deposited over all exposed top and bottom surfaces. The mask will be removed and an anti-reflective coating applied using a vapor-deposition or roll-on process. The complete solar cells will also be stored on take-up reels. The process is illustrated in Figure 2.2.3-3.

The weight, volume, and power required for the silicon ribbon processing apparatus, the control and data instrumentation, repair and maintenance equipment are given in Tables 2.2.3-1 through 2.2.3-5. The requirements for the solar cell processing apparatus are given in Table 2.2.3-5. These requirements are based on an average process optimization production rate of 9 kg/day.

(Text continued on page 137)

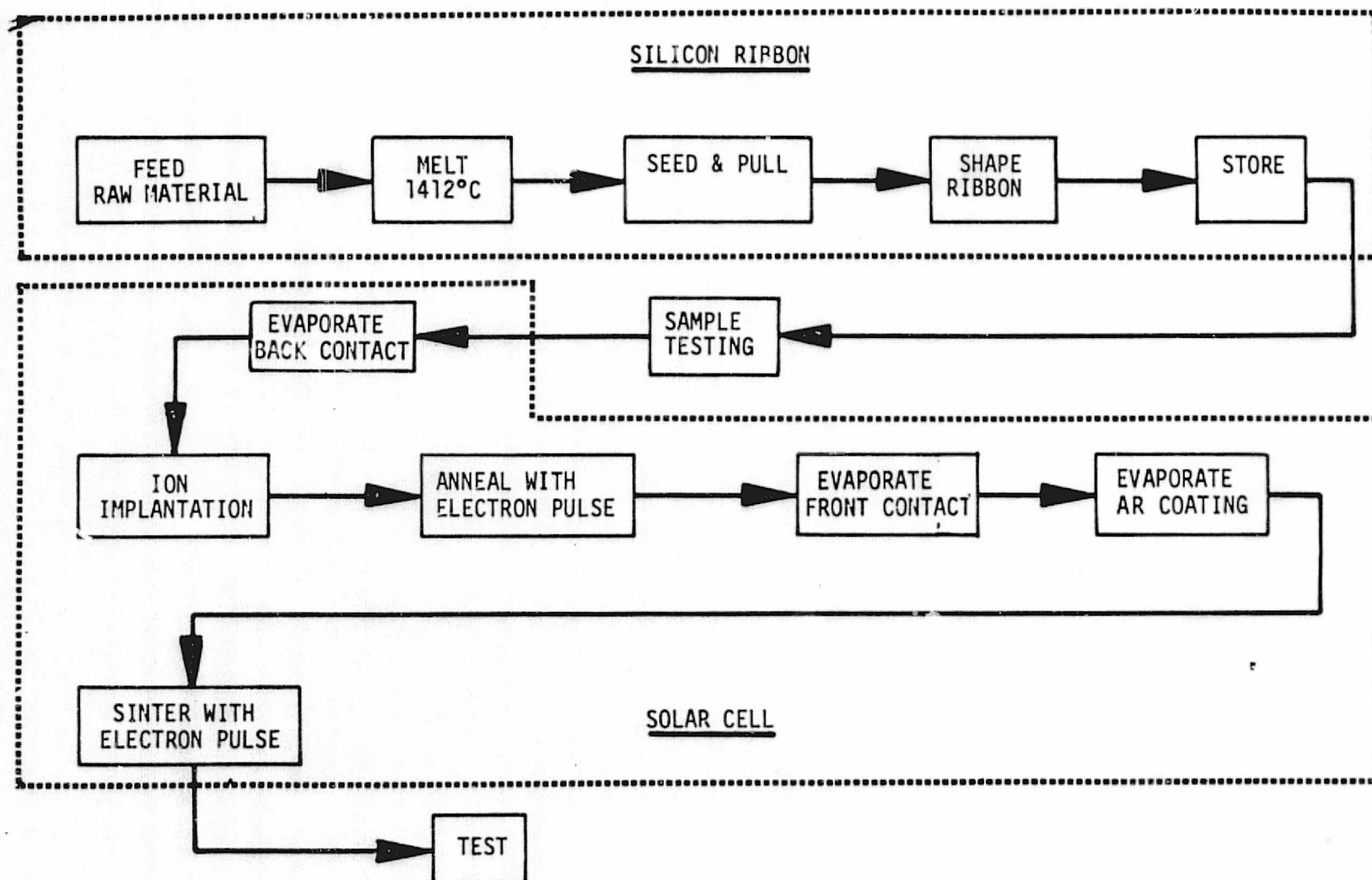


Figure 2.2.3-3. Solar Cell Manufacturing Process Flow



Table 2.2.3-1

## PROCESSING APPARATUS REQUIREMENTS

	Function	Processing Steps	Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status*
Shaped Crystal Processor** Furnace	Crystal Processing	All	700	15	4460	M
IR Photometer	Temperature Sensing	D and E	4.5	<0.01	50	M
IR TV Camera	Meniscus Shaping	B, C, and D	8	0.02	100	M
Noble Gas Supply	Crystal Processing	B, C, and D	240	0.32	0	M
RF Power Generator	Furnace Power Source	B, C, and D	185	0.25	1300	M
Crystal Puller	Ribbon Pull, Shaping	C	21	0.01	500	M
Camera & Accessories	Photographic Records	All	7	0.03	0	E
Auxiliary Furnace (1600°F)	Crystal Processing	For Standby Use (Not Shown)	21	0.01	500	M

\*M = Modified  
E = Existing

\*\*The shaped crystal processor includes the structure, feed rod mechanism, the crystal ribbon take-up reels and sample removal mechanism, controls and displays, the quality monitoring mechanism, the power conditioning unit, and connecting cables. The physical characteristics of this equipment have not yet been determined.

Table 2.2.3-2

CONTROL AND DATA INSTRUMENTATION

Function		Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status*
Computer	PDP-11 Type Including I/O and 32k Memory	46	0.08	100	M
Process Control and Data Handling					
Input/Output Multiplexer		8	0.01	22	E
CRT Display and Keyboard (2)	Operator Interface	18	0.08	20	M
Data Storage Tape (2)	Data Retention	21	0.01	30	E
Program Storage Tape	Analysis Routine	5	0.01	3	M
Data/Voice Formatter	Communication Interface	5	0.01	20	M

\*M = Modified

E = Existing

Table 2.2.3-3

## LABORATORY EQUIPMENT

	Function	Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status*
Variable Frequency, Constant Current Power Supply	Electrical Characterization	3	<0.01	100	M
High Gain Lock-in Amplifier	Electrical and Infrared Characterization	3	<0.01	50	M
High Gain DC Amplifier	Electrical Characterization	3	<0.01	50	M
Computer Plotter	Electrical and Infrared Characterization	8	0.2	150	M
Metallurgical Microscope	Structure Characterization	50	0.4	400	M
IR Spectrometer	Optical Characterization 1-1000 $\mu\text{m}$	100	0.6	1000	M
IR Recording Spectrometer	Optical Characterization 2-40 $\mu\text{m}$	60	0.1	150	M
Closed Cycle He Liquifier	Refrigeration From 1.2-300°K	100	0.1	1000	N
X-Ray Diffraction Apparatus	Crystal Structure	500	0.49	5000	M
Electromagnet and Field Regulated Power Supply	Electrical Characterization	100	0.84	1800	M
Capacitance Meter and C-U Plotter	Device Characterization	5	0.05	50	M

\*M - Modified

N - New

Table 2.2.3-3

LABORATORY EQUIPMENT (Continued)

	Function	Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status*
Digital Voltmeter	Electrical Characterization	1	<0.01	5	M
Liquid Helium Dewar With Optical Access	Electrical and Optical Characterization	5	0.2	0	M
IR Microscope	Crystal Morphology	80	0.4	500	M
Electron Microscope	Ribbon Characterization Crystal Morphology	2000	8.85	4	M
X-Ray Dispersive Microprobe	Ribbon Characterization	260	0.72	500	M
Auger Electron Spectrometer	Ribbon Surface Characterization	120	0.37	1000	M

\*M = Modified

Table 2. 2. 3-4

## REPAIR AND MAINTENANCE EQUIPMENT

Function		Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status*
Cutting, Polishing, Etching Facility	Sample Preparation	50	1	500	M
Jeweler's Lathe	Processor Modification	40	0.15	500	M
Drill	Processor Modification	3	0.01	600	E
Solder Tool	Maintenance	2	0.01	40	E
Bench Vise	Processor Modification	10	0.01	0	E
Hand Tools	Maintenance, Servicing	12	0.5	0	E

\*M = Modified

E = Existing

Table 2. 2. 3-5

## SOLAR CELL PROCESSING EQUIPMENT\*

	Function	Weight (kg)	Volume (m <sup>3</sup> )	Power (w)	Status**
Dopant Diffusion Chamber	Dopant Addition	56	4	50	N
Contact Diffusion Chamber	Solar Cell Contact	25	2	50	N
Anti-Reflection Coating Chamber	Anti-Reflection Coating	25	2	20	N
Shear	Remove Unwanted Ribbon	3	0.2	25	M
Storage Device	Store Completed Solar Cells	4.5	0.2	100	N
Ribbon Reel Drive	Control Ribbon	7	0.2	50	N
Pulsed Xenon Illuminator	Measure Cell Output	15	0.01	1000	N
Ion Implanter	Dopant and Contact Application	2200	12	10,000	M

\*Starting in 1986

\*\*N = New

M = Modified

The minimum volumetric requirements in 1984-85 for shaped crystal processing are as follows:

Silicon Ribbon Processing	32 m <sup>3</sup>
Raw Materials and Product Storage	2 m <sup>3</sup>
Spare Parts and Consumables Storage	15 m <sup>3</sup>
Crew Working Volume	40 m <sup>3</sup>
Miscellaneous Storage	<u>2 m<sup>3</sup></u>
Total	81 m <sup>3</sup>

A vacuum is required for the crystal processor furnace, the general-purpose furnace, the electron microscope, X-ray dispersive microprobe, auger electron spectrometer, and, in 1986, for the solar cell processor diffusion chambers. The vacuum port(s) shall provide  $10^{-7}$  torr at the equipment interfaces.

#### 2.2.3.3 Activity Description

All apparatus and instrumentation for the silicon ribbon processing will have been constructed and tested on the ground before it is sent to space. It will first be utilized in space on a 7-day Spacelab mission, and the processing operations will have been demonstrated on that flight.

Following the preliminary test, continuous on-orbit operation of the apparatus will be demonstrated on the Space Construction Base until stable operations have been attained. The apparatus will then be refurbished as required and any anomalies corrected on orbit. The production apparatus and associated test and evaluation equipment will be installed in the shaped crystals processing module, where process optimization and initial production will be done.

The optimization efforts are tentatively scheduled for 1984, before initial production begins in 1985. Full-scale production will commence the following year. To make the process work, and to make it work more effectively after production is underway, the following activities will be conducted during optimization and production: (1) fine-tune the process apparatus; (2) optimize the shaped-crystal process; (3) determine the effects of operational transients (e. g. , shock and acceleration) on the end product, and (4) evaluate methods

of controlling the end-product configuration (e. g. , shape or orientation) during processing. The specific tasks involved in these activities are shown in Figure 2.2.3-4.

The evaluations of the end-product will be made on ribbon samples, other than those extracted for automated quality checks. Typical procedures involved in the electrical and physical characterizations of the samples are shown in Figure 2.2.3-5.

In addition, procedures for servicing and maintaining the process apparatus will need to be prepared, a method of in-orbit solar cell production will need to be developed, and alternate material processing will need to be evaluated. Alternate materials might include gallium arsenide (for solar cells) indium antimonide (infrared sensors), lithium niobate (waveguides), and yttrium aluminum garnet (lasers). The tasks involved in the evaluation of such alternate materials are shown in Figure 2.2.3-6.

The continuous processing of silicon ribbon and the cyclical processing of alternate materials are noted in the schedule shown in Figure 2.2.3-7.

#### 2.2.3.4 Space Construction Base Requirements

##### Power

The total power requirements from the SCB are shown in Figure 2.2.3-8. The peak power required reflects use of all laboratory equipment as well as processing apparatus.

##### Environmental Control

Temperature and humidity requirements for the module are those for SCB shirtsleeve activity. Conditions of a Class 10,000 clean room per FED-STD-209 are required. Furnace cooling is to be provided by a closed-loop coolant system.

##### Acceleration and Noise Control

During ribbon processing, acceleration must be maintained at less than  $10^{-3}$  g and the acoustic level must be less than 70 db.

(Text continued on page 154)



	OBJECTIVE	EQUIPMENT	84	85	86	87	88	89
RIBBON CHARACTERIZATION	EVALUATE ELECTRICAL AND STRUCTURAL PROPERTIES OF FABRICATED RIBBON	IR SPECTROMETER AND ACCESSORIES, IR MICROSCOPE, ELECTRICAL CHARACTERIZATION APPARATUS FOR TEMPERATURE RANGE OF 4 TO 400K, X-RAY DIFFRACTION APPARATUS, ELECTRON MICROSCOPE, X-RAY ENERGY -- DISPERSIVE MICROPROBE, AUGER-ELECTRON SPECTROMETER MICRO-CIRCUIT TEST FACILITY						
MENISCUS SHAPING RF SHAPING DUAL RIBBONS	DETERMINE OPTIMUM SHAPING CONDITIONS FOR SIMULTANEOUS SHAPING OF TWO RIBBONS	FURNACE, CAMERAS, IR PHOTOMETRIC EQUIPMENT, TEMPERATURE MONITORING AND CONTROLLING DEVICES, IR TV CAMERAS, DATA PROCESSING AND TRANSMITTING ELECTRONICS, CRYSTAL PULLING ASSEMBLY, RF POWER GENERATORS, ARGON GAS SUPPLY AND REGULATORS, REMOTE CONTROL MICROMANIPULATORS, RF POWER STABILIZERS, REMOTE FEED ROD MANIPULATORS.						
FEED ROD MECHANISM	DEMONSTRATE FEEDING CAPABILITY OF MECHANISM AND ROD STORAGE CANISTER, DEMONSTRATE THE CREWMAN'S ABILITY TO RELOAD THE FEED ROD CANISTERS, OBSERVE MELT REACTION TO FEED ROD JUNCTION.	PROCESSOR PROTOTYPE CREWMAN EVA EQUIPMENT, VIBRATION PICK-UPS, TV CAMERAS, TEMPERATURE RECORDERS, IR PHOTOMETRIC EQUIPMENT, DATA RECORDER						
RIBBON TAKE-UP AND REEL	EVALUATE RIBBON TAKE-UP STORAGE AND REEL TRANSFER CONCEPT UNDER SPACE ENVIRONMENT, SYNCHRONIZE RIBBON TAKE-UP SPEED WITH RIBBON PULL RATE.	PROCESSOR PROTOTYPE, TV CAMERAS, CREWMAN EVA EQUIPMENT.						

Figure 2.2.3-4. Evaluations of Silicon Ribbon (Sheet 1 of 3)

	OBJECTIVE	EQUIPMENT	84	85	86	87	88	89
RIBBON-SHAPING NON-WETTING	EVALUATE FEASIBILITY OF USING NON-WETTING DIES FOR SHAPING PROCESS	FURNACE, CAMERAS, IR PHOTOMETRIC EQUIPMENT, IR CAMERAS, TEMPERATURE MONITORING AND CONTROLLING DEVICES, DATA PROCESSING AND TRANSMITTING ELECTRONICS, CRYSTAL PULLING ASSEMBLIES, ARGON GAS SUPPLY, FLOW REGULATORS, REMOTE CONTROL MICROMANIPULATORS, REMOTE FEED - ROD MANIPULATORS.						
PROCESS SYSTEM EVALUATION	OPERATIONAL TEST OF PROCESS APPARATUS	PROTOTYPE PROCESS APPARATUS						
FURNACE WITH AUXILIARY HEATERS	VERIFY FURNACE AND AUXILIARY HEATERS	FURNACE PROTOTYPE, IR PHOTO-METRIC EQUIPMENT, IR CAMERA TEMPERATURE CONTROLLING AND MONITORING DEVICES, ARGON GAS SUPPLY, DATA RECORDER.						
RIBBON PULL CHAMBER	GATHER DATA FOR FINE TUNNING AND REGULATING THE PULL CHAMBER CONTROLS	FURNACE, PULL CHAMBER PROTOTYPE, IR PHOTOMETER EQUIPMENT, IR CAMERAS, TEMPERATURE CONTROLLING AND MONITORING DEVICES, ARGON GAS SUPPLY, PULL CHAMBER CONTROLLER, DATA RECORDER						
PROCESS MONITOR AND CONTROL	EVALUATE THE CONCEPT AND OPERATION OF THE PROCESS MONITOR AND CONTROL FEEDBACK LOOPS IN SPACE ENVIRONMENT.	PROCESS PARAMETER SENSORS, ACTUATORS/CONTROLLERS, SIGNAL CONDITIONER, REMOTE MULTIPLEXER, REMOTE DECODER, ONBOARD COMPUTER, PROCESSOR PROTOTYPE, DATA RECORDER.						
SEED/RESEED MECHANISM	DEMONSTRATE THE MECHANISM CAN SEED/RESEED THE MELT TO START PROCESS	PROCESSOR PROTOTYPE, MONITOR AND CONTROL, PARAMETER SENSORS, SIGNAL CONDITIONER, ONBOARD COMPUTER, REMOTE MULTIPLEXER, REMOTE DECODER, DATA RECORDER.						
RIBBON REJECT MECHANISM	DEMONSTRATE REJECT MECHANISM TO CUT AND REJECT SEED AND POOR QUALITY RIBBON	PROCESSOR PROTOTYPE, DATA RECORDER, ONBOARD COMPUTER, TV CAMERA						

Figure 2.2.3-4. Evaluations of Silicon Ribbon (Sheet 2 of 3)

INVESTIGATION	OBJECTIVE	EQUIPMENT	84	85	86	87	88
SHOCK TEST	DETERMINE EFFECTS OF CONTROLLED DISTURBANCES ON SHAPING PROCESS	PROTOTYPE PROCESSOR ACCELEROMETERS, RIBBON CHARACTERIZATION EQUIPMENT					
ACCELERATIONS	DETERMINE EFFECTS OF TRANSIENT ACCELERATIONS ON SHAPING PROCESS						
PRODUCT CONFIGURATION CONTROL SIZE/SHAPE	DETERMINE EFFECT OF PULL-RATE, RF FIELD INTENSITY, MELT TEMPERATURE SEED ORIENTATION, ETC., ON RIBBON TOPOLOGY	RIBBON CHARACTERIZATION EQUIPMENT					
DEFECT DENSITY AND DISTRIBUTION	DETERMINE THE EFFECT OF VARIATIONS IN SHAPING CONDITIONS ON CRYSTAL DEFECT DENSITIES & THEIR SPECIAL DISTRIBUTION						
DOPANTS	DETERMINE EFFECT OF VARIATIONS IN SHAPING CONDITIONS ON DOPANT HOMOGENITY						

Figure 2.2.3-4. Evaluation of Silicon Ribbon (Sheet 3 of 3)

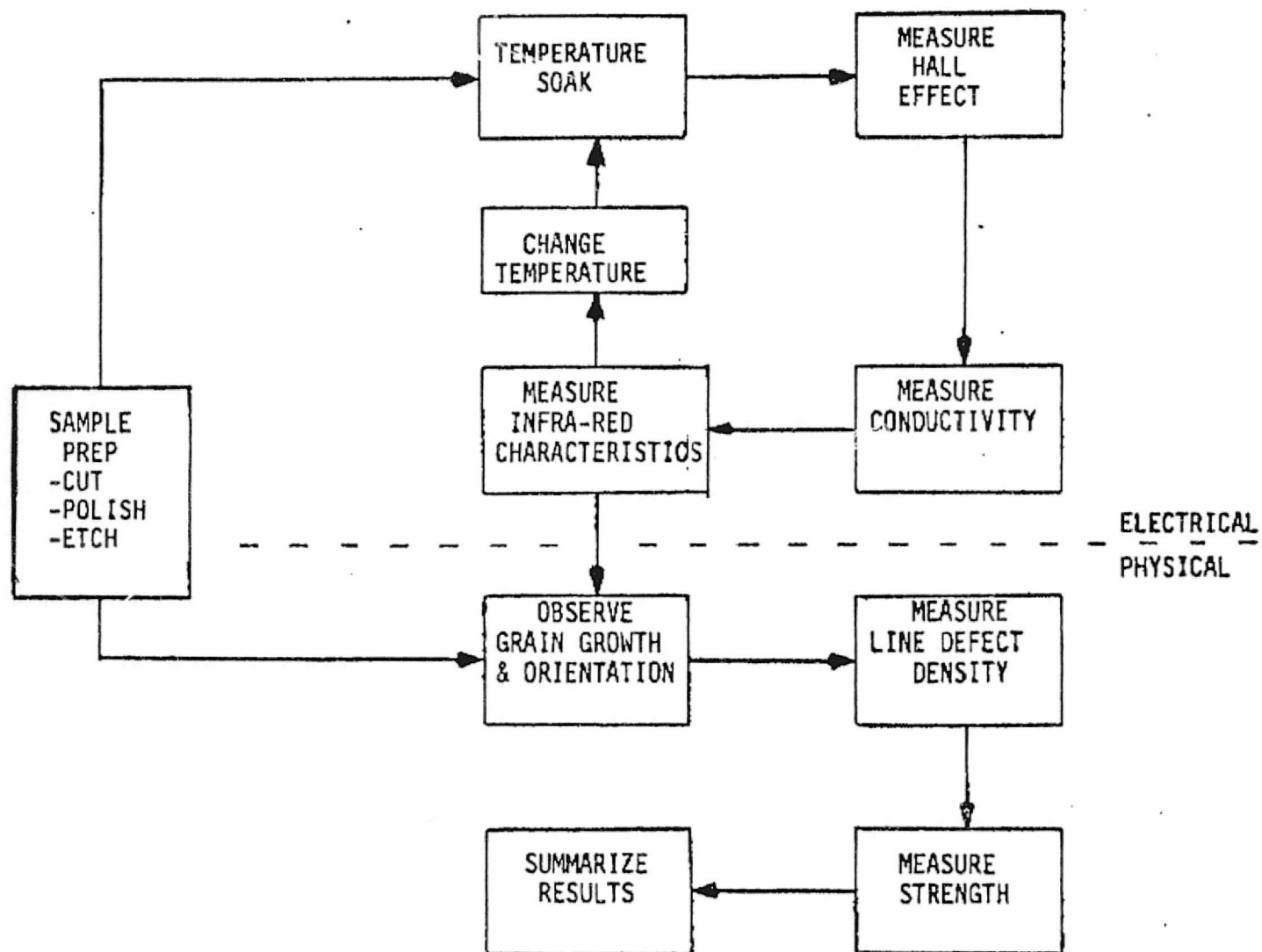


Figure 2.2.3-5. Product Analysis

INVESTIGATION	OBJECTIVE	EQUIPMENT	85	86	87	88	89
<u>ELECTRICAL PROPERTIES</u> HALL COEFFICIENT	DETERMINE TEMPERATURE DEPENDENCE OF HALL	A.C. CONSTANT CURRENT POWER SUPPLY, LOCK-IN AMPLIFIER, MAGNET, VARIABLE TEMP LIQ He DEWAR, CLOSE-CYCLE He LIQUIFIER, CUTTING & POLISHING FACILITY, ON-LINE COMPUTER					
CONDUCTIVITY	COEFFICIENT MEASURE TEMPERATURE DEPENDENCE OF CONDUCTIVITY BETWEEN 1.2 & 500K						
CARRIER MOBILITIES	EVALUATE TEMPERATURE DEPENDENCE OF CARRIER MOBILITIES & IMPORTANCE OF SCATTERING MECHANISMS						
OPTICAL PROPERTIES	MEASURE TEMPERATURE DEPENDENCE OF IR ABSORPTION COEFFICIENTS/WAVELENGTH BETWEEN 4.0 TO 300K TO IDENTIFY IMPURITY	IR SPECTROMETER, ON-LINE COMPUTER, VARIABLE TEMP LIQ He DEWAR W/OPTICAL WINDOWS, CLOSE-CYCLE He LIQUIFIER, CUTTING & POLISHING FACILITY					

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 1 of 7)

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INVESTIGATION			1985	1986	1987	1988
	OBJECTIVE	EQUIPMENT				
MELT STABILITY AND LIQUID-SOLID INTERFACE	DETERMINE THE TOPOLOGY OF THE LIQUID-SOLID INTERFACE IN MICRO GRAVITY	FURNACE AND TEMPERATURE CONTROL SYSTEM, PRECISE TEMPERATURE MONITORING SYSTEM, CAMERAS, PRESSURE SENSORS, ARGON GAS SUPPLY, DATA COLLECTING ELECTRONICS.				
MELT SEED INTERACTION	DETERMINE VARIATION OF MENISCUS SHAPE AND ATTACHMENT ANGLE WITH MENISCUS HEIGHT	FURNACE AND TEMPERATURE CONTROL SYSTEM, TEMPERATURE MONITORING EQUIPMENT, PRESSURE SENSORS, ARGON GAS SUPPLY, DATA COLLECTING ELECTRONICS				
CRYSTAL GROWTH	DETERMINE VARIATION OF MENISCUS SHAPE AND GROWTH ANGLE WITH SEED PULL RATE IN MICRO-GRAVITY.	FURNACE AND TEMPERATURE CONTROL SYSTEM, TEMPERATURE MONITORING EQUIPMENT, PRESSURE SENSORS, ARGON GAS SUPPLY, CRYSTAL INSERTION AND PULLING ASSEMBLY, DATA COLLECTING ELECTRONICS				

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 2 of 7)



INVESTIGATION			1985	1986	1987	1988
	OBJECTIVE	EQUIPMENT				
SOLID-LIQUID INTERFACIAL TOPOLOGY	DETERMINE THE GEOMETRY OF THE ISOTHERMAL SURFACES DURING SOLIDIFICATION IN MICRO-GRAVITY	SOUNDING ROCKET, FURNACE AND TEMPERATURE CONTROL SYSTEM, TEMPERATURE MONITORING EQUIPMENT, PRESSURE SENSORS, ARGON GAS SUPPLY, CRYSTAL INSERTION PULLING ASSEMBLY, DATA COLLECTING MONITORING ELECTRONICS INFRARED MICROSCOPE, RADIOACTIVE - COUNTING EQUIPMENT.				
CRYSTAL MORPHOLOGY	EVALUATE THE EFFECT OF MICRO-GRAVITY ON CRYSTAL MORPHOLOGY OF RECRYSTALLIZED SILICON	INFRARED MICROSCOPE, X-RAY DIFFRACTION APPARATUS, ELECTRON MICROSCOPE, X-RAY ENERGY-DISPERSIVE MICROPROBE, AUGER ELECTRON SPECTROMETER				
MENISCUS SHAPING, RADIO-FREQUENCY	DEMONSTRATE THE FEASIBILITY OF SHAPING PLANAR SHEETS (RIBBON) OF SILICON IN MICRO-GRAVITY USING RF FORCES	SOUNDING ROCKET, HIGH TEMPERATURE FURNACE, TEMPERATURE MONITORING AND CONTROLLING EQUIPMENT, RF POWER SUPPLY AND RELATED ELECTRONICS, DATA COLLECTION AND RECORDING ELECTRONICS				
MENISCUS SHAPING, NON-WETTING DIES	IDENTIFY HIGH TEMPERATURE MATERIALS THAT MAY SERVE AS NON-WETTING DIES FOR SILICON RIBBON PROCESSING IN MICRO-GRAVITY. DEMONSTRATE THE FEASIBILITY OF RIBBON SHAPING USING NON-WETTING DIES	SOUNDING ROCKET, FURNACE, TEMPERATURE MONITORING AND CONTROLLING EQUIPMENT, ARGON GAS SUPPLY, CAMERAS AND RELATED OPTICAL EQUIPMENT, DATA PROCESSING AND RECORDING ELECTRONICS, APPARATUS TO DETERMINE IMPURITY CONCENTRATIONS AND THEIR ELECTRICAL ACTIVITIES				

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 3 of 7)

INVESTIGATION			1985	1986	1987	1988	1989
	OBJECTIVE	EQUIPMENT					
MELT-FEED ROD INTERACTION	DETERMINE MELT SHAPE, TEMPERATURE DISTRIBUTION IN MELT AND RODS, MELT STABILITY AS FUNCTION OF MELT TEMPERATURE AND INERT GAS PRESSURE	VACUUM FURNACE, CAMERAS, INFRARED PHOTOMETRIC EQUIPMENT, TEMPERATURE MONITORING AND CONTROLLING DEVICES, DATA PROCESSING AND TRANSMITTING ELECTRONICS, INFRARED TELEVISION CAMERAS, FAST RESPONSE SENSING DEVICES.					
MENISCUS SHAPING - RF	EVALUATE CRITICAL PARAMETERS FOR CONTINUOUS SILICON RIBBON GROWTH IN SPACE	VACUUM FURNACE, CAMERAS IR PHOTO-METRIC EQUIPMENT, TEMPERATURE MONITORING AND CONTROLLING DEVICE, IR TV CAMERAS, DATA PROCESSING AND TRANSMITTING ELECTRONICS, CRYSTAL PULLING ASSEMBLY, RF POWER GENERATOR, ARGON GAS SUPPLY AND REGULATORS, REMOTE CONTROL MICRO-MANIPULATORS, REMOTE FEED ROD MANIPULATORS.					
MENISCUS SHAPING RF SHAPING DUAL RIBBONS	DETERMINE OPTIMUM SHAPING CONDITIONS FOR SIMULTANEOUS SHAPING OF TWO RIBBONS	SOLAR FURNACE, CAMERAS, IR PHOTO-METRIC EQUIPMENT, TEMPERATURE MONITORING AND CONTROLLING DEVICES, IR TV CAMERAS, DATA PROCESSING AND TRANSMITTING ELECTRONICS, CRYSTAL PULLING ASSEMBLY, RF POWER GENERATORS, ARGON GAS SUPPLY AND REGULATORS, REMOTE CONTROL MICROMANIPULATORS, RF POWER STABILIZERS, REMOTE FEED ROD MANIPULATORS.					
RIBBON CHARACTERIZATION	EVALUATE ELECTRICAL AND STRUCTURAL PROPERTIES OF FABRICATED RIBBON	IR SPECTROMETER AND ACCESSORIES, IR MICROSCOPE, ELECTRICAL CHARACTERIZATION APPARATUS FOR TEMPERATURE RANGE OF 4 TO 400K, X-RAY DIFFRACTION APPARATUS, ELECTRON MICROSCOPE, X-RAY ENERGY - DISPERSIVE MICROPROBE, AUGER-ELECTRON SPECTROMETER MICRO-CIRCUIT TEST FACILITY					

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 4 of 7)



	OBJECTIVE	EQUIPMENT	1985	1986	1987	1988	1989
RIBBON-SHAPING NON-WETTING	EVALUATE FEASIBILITY OF USING NON-WETTING DIES FOR SHAPING PROCESS	FURNACE, CAMERAS, IR PHOTOMETRIC EQUIPMENT, IR CAMERAS, TEMPERATURE MONITORING AND CONTROLLING DEVICES, DATA PROCESSING AND TRANSMITTING ELECTRONICS, CRYSTAL PULLING ASSEMBLIES, ARGON GAS SUPPLY, FLOW REGULATORS, REMOTE CONTROL MICROMANIPULATORS, REMOTE FEED - ROD MANIPULATORS.					
SOLAR FURNACE WITH AUXILIARY HEATERS	VERIFY SOLAR FURNACE AND AUXILIARY HEATERS	FURNACE PROTOTYPE, IR PHOTOMETRIC EQUIPMENT, IR CAMERA TEMPERATURE CONTROLLING AND MONITORING DEVICES, ARGON GAS SUPPLY, DATA RECORDER.					
RIBBON PULL CHAMBER	GATHER DATA FOR FINE TUNNING AND REGULATING THE PULL CHAMBER CONTROLS	FURNACE, PULL CHAMBER PROTOTYPE, IR PHOTOMETER EQUIPMENT, IR CAMERAS, TEMPERATURE CONTROLLING AND MONITORING DEVICES, ARGON GAS SUPPLY, PULL CHAMBER CONTROLLER, DATA RECORDER					
PROCESS MONITOR AND CONTROL	EVALUATE THE CONCEPT AND OPERATION OF THE PROCESS MONITOR AND CONTROL FEEDBACK LOOPS IN SPACE ENVIRONMENT.	PROCESS PARAMETER SENSORS, ACTUATORS/CONTROLLERS, SIGNAL CONDITIONER, REMOTE MULTIPLEXER, REMOTE DECODER, ONBOARD COMPUTER, PROCESSOR PROTOTYPE, DATA RECORDER.					
SEED/RESEED MECHANISM	DEMONSTRATE THE MECHANISM CAN SEED/RESEED THE MELT TO START PROCESS	PROCESSOR PROTOTYPE, MONITOR AND CONTROL, PARAMETER SENSORS, SIGNAL CONDITIONER, ONBOARD COMPUTER, REMOTE MULTIPLEXER, REMOTE DECODER, DATA RECORDER.					
RIBBON REJECT MECHANISM	DEMONSTRATE REJECT MECHANISM TO CUT AND REJECT SEED AND POOR QUALITY RIBBON	PROCESSOR PROTOTYPE, DATA RECORDER, ONBOARD COMPUTER, TV CAMERA					

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 5 of 7)

	OBJECTIVE	EQUIPMENT	1985	1986	1987	1988	1989
FEED ROD MECHANISM	DEMONSTRATE FEEDING CAPABILITY OF MECHANISM AND ROD STORAGE CANISTER, DEMONSTRATE THE CREWMAN'S ABILITY TO RELOAD THE FEED ROD CANISTERS, OBSERVE MELT REACTION TO FEED ROD JUNCTION.	PROCESSOR PROTOTYPE CREWMAN EVA EQUIPMENT, VIBRATION PICK-UPS, TV CAMERAS, TEMPERATURE RECORDERS, IR PHOTOMETRIC EQUIPMENT, DATA RECORDER					
RIBBON TAKE-UP AND REEL	EVALUATE RIBBON TAKE-UP STORAGE AND REEL TRANSFER CONCEPT UNDER SPACE ENVIRONMENT, SYNCHRONIZE RIBBON TAKE-UP SPEED WITH RIBBON PULL RATE.	PROCESSOR PROTOTYPE, TV CAMERAS, CREWMAN EVA EQUIPMENT.					

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 6 of 7)

INVESTIGATION	OBJECTIVE	EQUIPMENT	85	86	87	88	89
<u>STRUCTURAL CHARACTERIZATION</u> CRYSTALLOGRAPHIC ORIENTATION & GRAIN GROWTH	DETERMINE CRYSTAL ORIENTATIONS & GRAIN SIZES FOR VARIOUS CONDITIONS	X-RAY DIFFRACTION APPARATUS, CAMERA, METALLURGICAL MICROSCOPE, CUTTING & POLISHING FACILITY AND ELECTRON MICROSCOPE	<hr/> <hr/>				
DENSITY OF LINE DEFECTS	DETERMINE DENSITY & DISTRIBUTION OF LINE DEFECTS UNDER VARIOUS CONDITIONS		<hr/> <hr/>				
OVERALL PRODUCT EVALUATION	CORRELATE THE RESULTS WITH PROCESS PARAMETERS TO DETERMINE OPTIMUM PARAMETERS	ON-BOARD COMPUTER			<hr/> <hr/>		

Figure 2.2.3-6. Evaluations of Alternate Materials (Sheet 7 of 7)

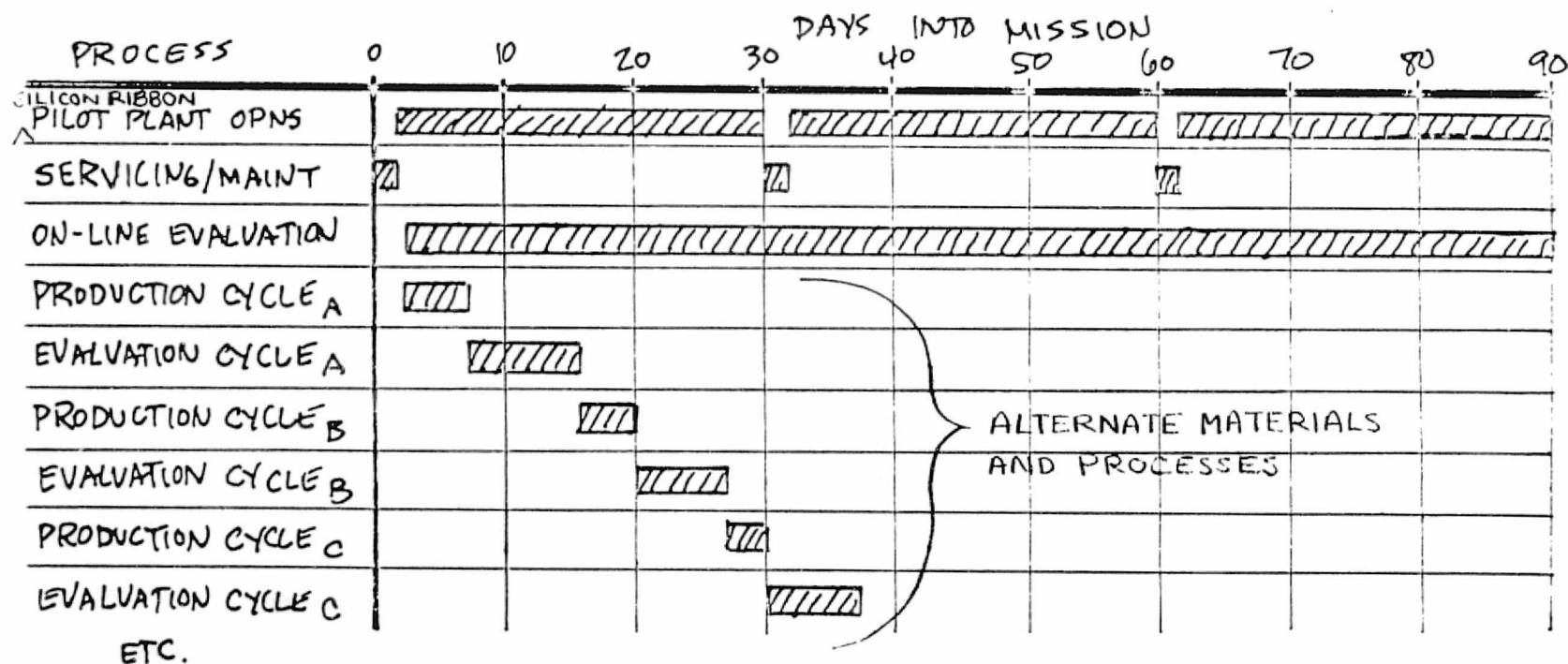


Figure 2.2.3-7. Processing Schedule Case Example  
(Shaped Crystals Produced During Mission)

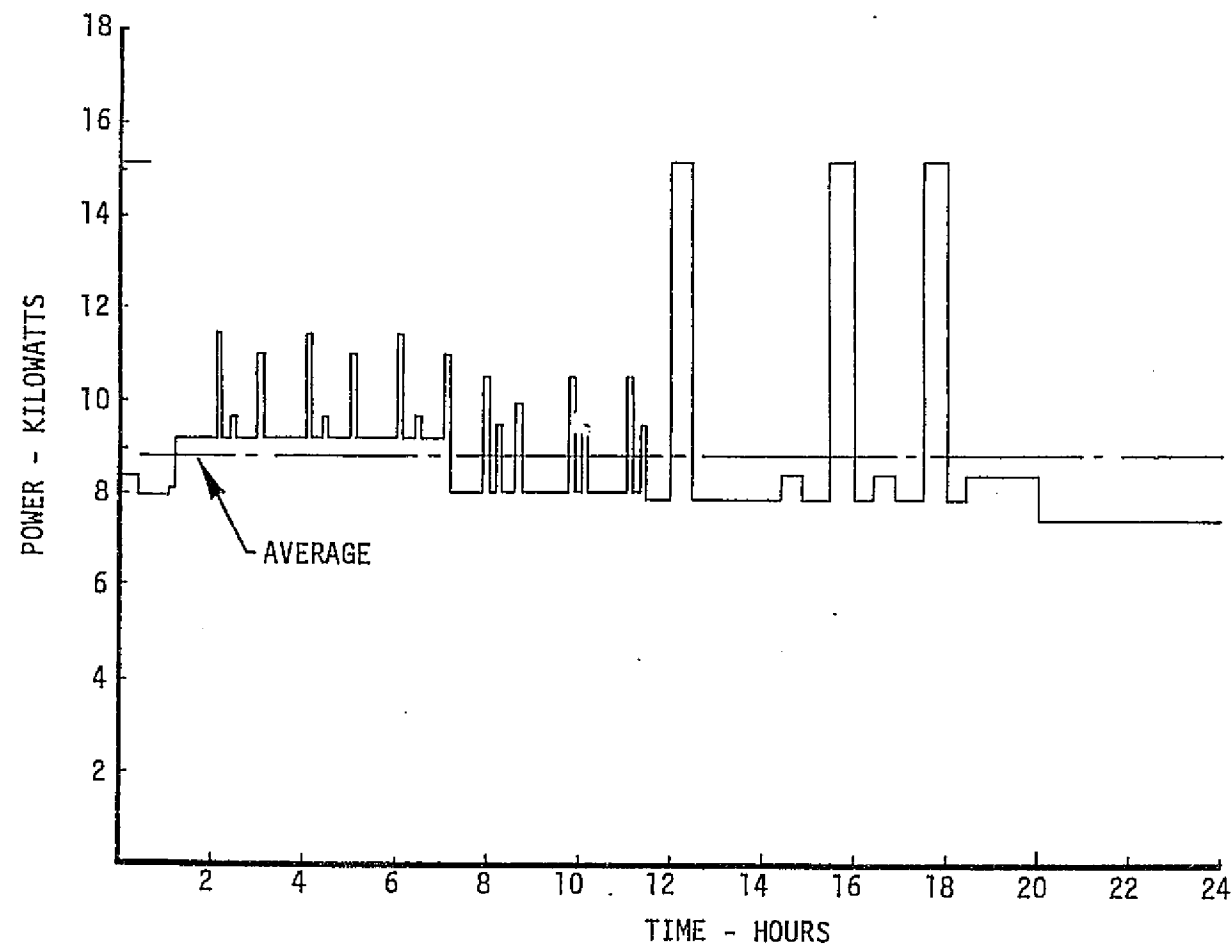


Figure 2.2.3-8. Shaped Crystal Power Profile — Typical 1984 Day (Sheet 1 of 3)

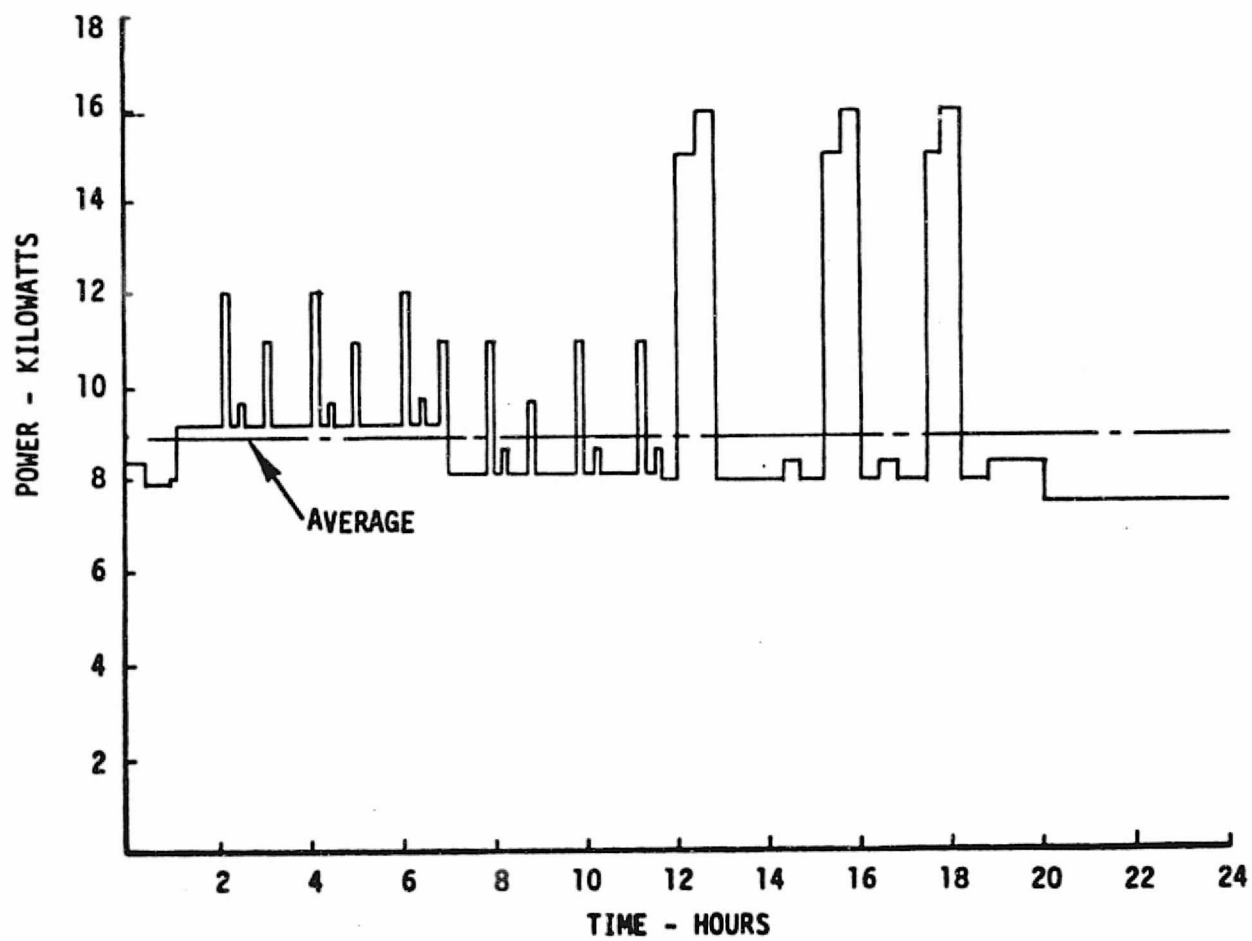


Figure 2.2. 3-8. Shaped Crystal Power Profile — Typical 1984 Day (Sheet 2 of 3)

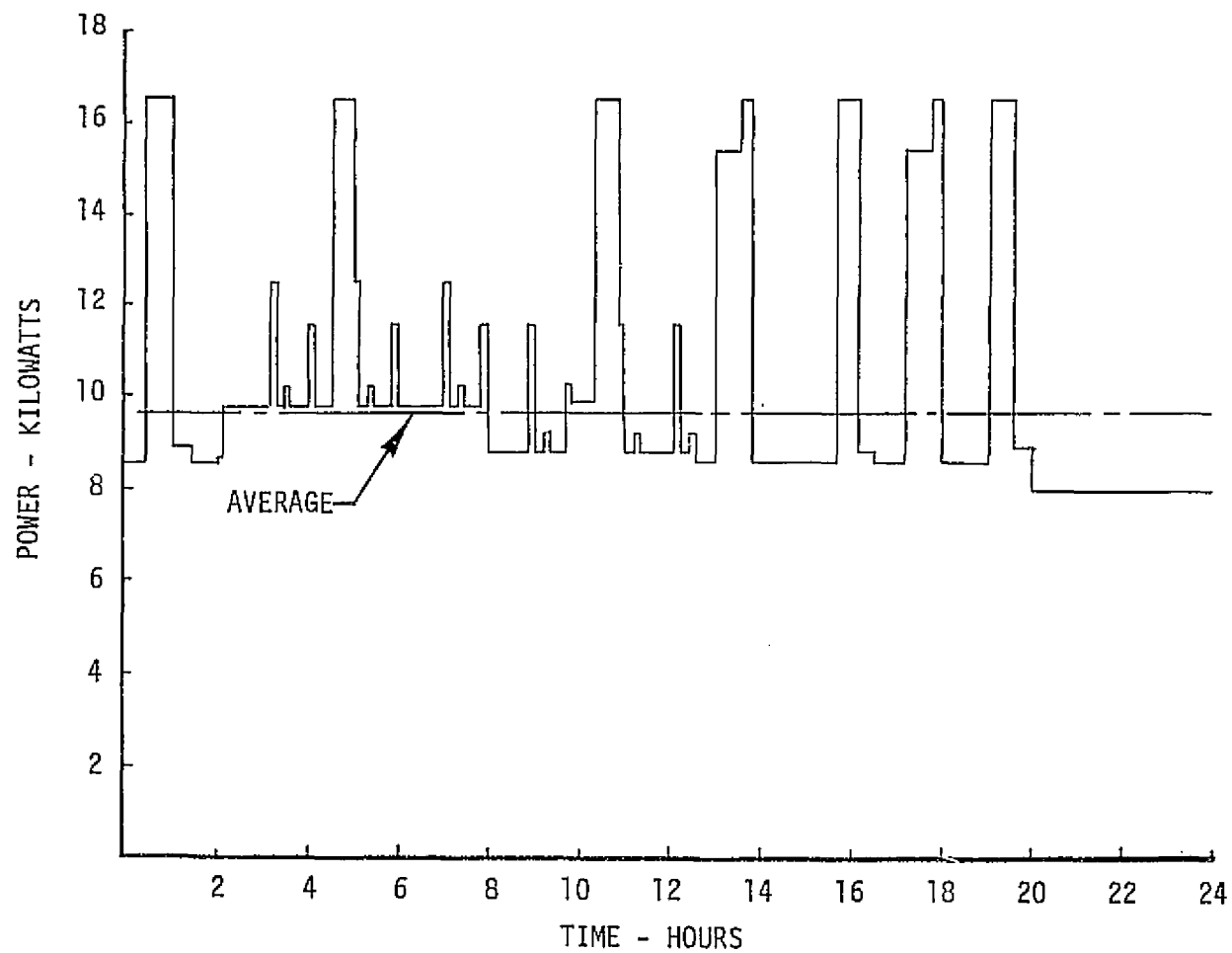


Figure 2.2.3-8. Shaped Crystal Power Profile — Typical 1986 Day (Sheet 3 of 3)

### Data Management/Communications

Requirements on the SCB in addition to a secure voice link to ground will be a digital link capable of transmitting 10 kb of process and test data to the ground each day.

### Safety

Hazardous conditions and materials associated with shaped crystal processing include a potential loss of process control (e. g. , overheating, loss of levitation, and overpressure), leakage of phosphene gas or arsenic trioxide, or spills during chemical analyses or transfers of reagents.

Measures to preclude or limit hazards to personnel and equipment will include: (1) sensors to detect any leakage of gases; (2) location of hazardous materials in isolated areas, and (3) provision for evacuation of personnel and sealing off the processing module from the SCB proper.

### Personnel

The manpower requirements for process optimization and production are:

<u>Phase</u>	<u>Technician</u>	<u>Material Scientist</u>
Process Optimization	1	2
Production	2	4

Two shifts per day of 10 hours each will be used during optimization. Around-the-clock operations will be typical during production. In the production phases, crews will rotate each 90 days. No additional manpower will be required for solar cell production or for processing of alternate materials.

### Logistics

During the process optimization phase, approximately 1000 kg of raw materials and supplies and 800 kg of equipment and spare parts will be required to be delivered to the processing module each 90 days. These items will occupy  $2 \text{ m}^3$  and  $15 \text{ m}^3$ , respectively. Approximately 800 kg ( $2 \text{ m}^3$ ) of finished product will be returned each 90 days.



## 2.3 EARTH SERVICES

The Earth Services objective is concerned with earth observation, communication, and navigation applications for earth-orbiting satellites. The economic and social benefits of these applications have been recognized and enjoyed for many years. Even greater benefits can be expected from improved satellite communication and observation systems.

These improved systems will generally involve more complex satellites with much larger antennas. The antennas required for many of the future Earth Services applications are too large to be erected by current unfurling techniques. They must be assembled in space by construction crews. Further, the tolerance constraints will require in-space alignment and calibration. Because of the complexity and expense of future Earth Services satellites, it will become cost-effective to prolong their lives by periodic maintenance and servicing - a function that will be supported by the Space Construction Base (SCB). In addition, the SCB will be required to support radiometer and communications system development tests that exceed Shuttle mission durations.

To help define the SCB requirements, two representative Earth Services systems have been examined: an earth observation microwave radiometer requiring a large parabolic antenna, and an electronic mail or personal communications system requiring a large, multiple-beam antenna.

### 2.3.1 30-Meter Radiometer

#### 2.3.1.1 Mission Overview

A long-wavelength microwave radiometry satellite will be constructed to measure thermal emissions from the earth's atmosphere and surface in order to obtain data on soil moisture, snow coverage, sea states, and the atmosphere. These data will be utilized in forecasts of water availability, global crop predictions, and climatology studies. The radiometer will feature an antenna 30 m in diameter, a solar array panel to capture energy for power, and high-resolution microwave sensors. It will operate at an inclination of 50 deg and an altitude of from 340 to 800 km. The 30-m radiometer will serve to demonstrate the feasibility of fabricating larger systems in the 1980's which will employ antennas 100 to 600 m in diameter.

### 2.3.1.2 Mission Hardware Description

Figure 2.3.1-1 illustrates the major components of the radiometer and the method of assembly.

The radiometer is to operate at microwave frequencies of 0.6 to 118 GHz. It will contain 28 radiometry channels providing both horizontal and vertical polarization, and be capable of scanning over an angle of 100 degrees.

The surface tolerance to be maintained has been set at 0.13 cm. The tolerance is based upon obtaining 1-km resolution (at a frequency of 10 GHz and an altitude of 340 km) with a pattern which is degraded no more than 1 db. Higher frequencies naturally provide increased resolution, but their patterns will suffer correspondingly greater degradation with this surface tolerance. Lower-frequency beam patterns will be degraded less than 1 db.

The satellite configuration and characteristics are shown in Figure 2.3.1-2. The 30-m parabolic torus antenna was selected because of its scanning capability. It employs a Gregorian-type feed system with a primary focal length of 7.5 m and an effective focal length of 15 m provided by an elliptic secondary mirror. Mass properties for the radiometer are shown in Figure 2.3.1-3.

The facing material (skins) on the prefabricated antenna parabolic panel segments will be GY70 preimpregnated graphite fiber. This particular type of fiber was selected because of its low coefficient of expansion,  $\alpha$ , — about  $-0.3 \times 10^{-6}$  cm/cm/°C ( $-0.6 \times 10^{-6}$  in/in/°F). Laminated structures typically yield an  $\alpha$  between 0 and  $+0.6 \times 10^{-6}$  cm/cm/°C ( $+1 \times 10^{-6}$  in/in/°F), depending on fiber orientation. Bi-directionally woven fabric, coated with epoxy resin, is the preferred textile form. GY70 or an equivalent type of graphite fiber will also be used for the antenna structure because of its low  $\alpha$  and high stiffness. The required textile form will be continuous fiber yarn or roving (untwisted material in yarn form) because of the contemplated manufacturing process for truss members.

Prefabricated edge closeout members will also be used on the antenna. These members will be trimmed and assembled with the preformed panel segments

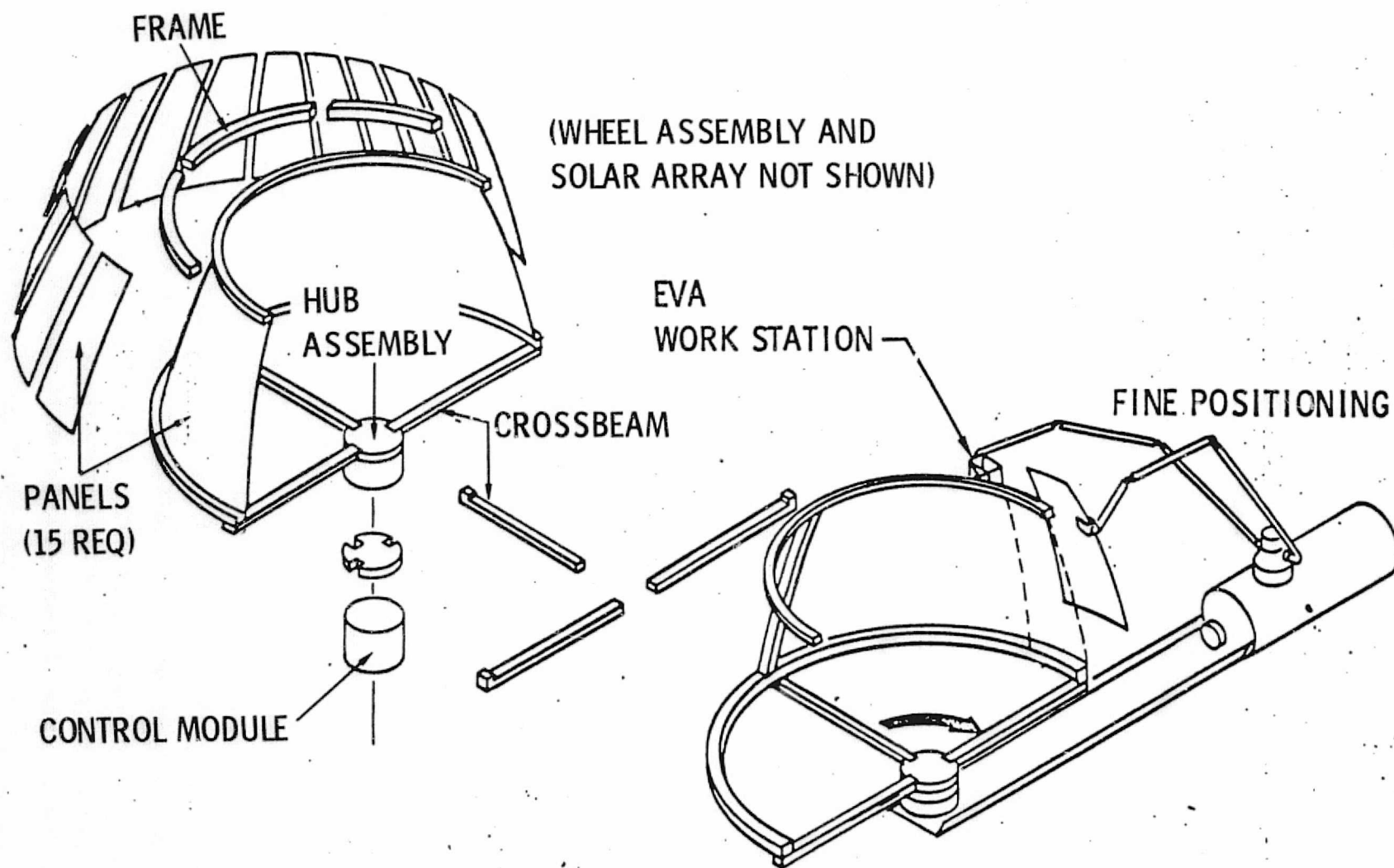
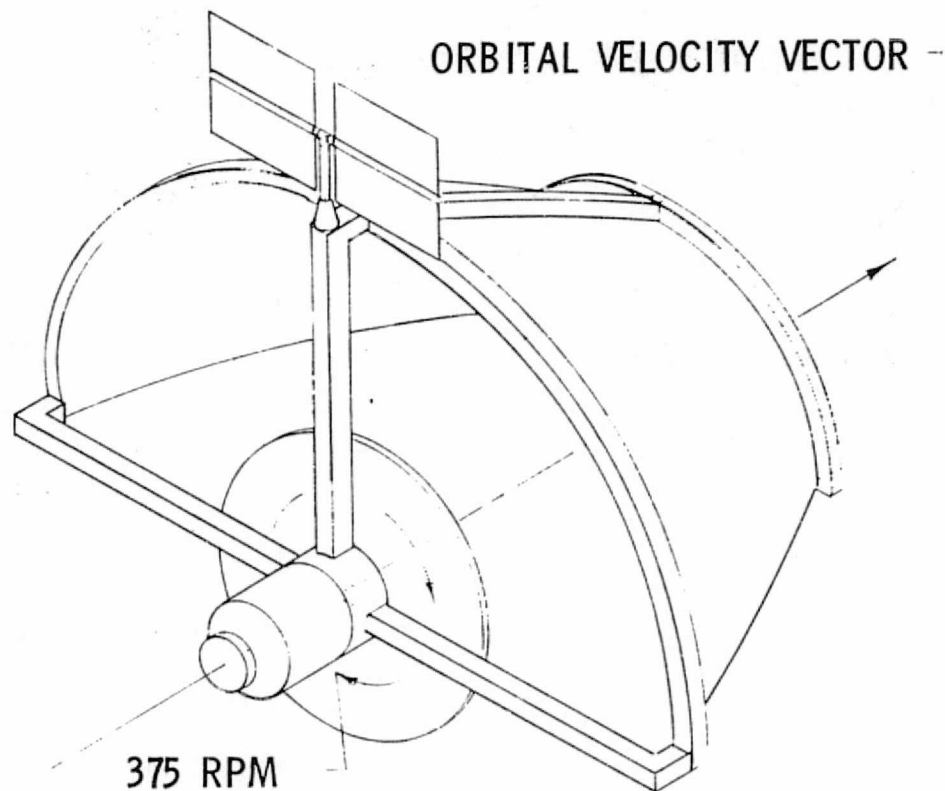


Figure 2.3.1-1. 30-Meter Radiometer On-Orbit Assembly

CHARACTERISTICS

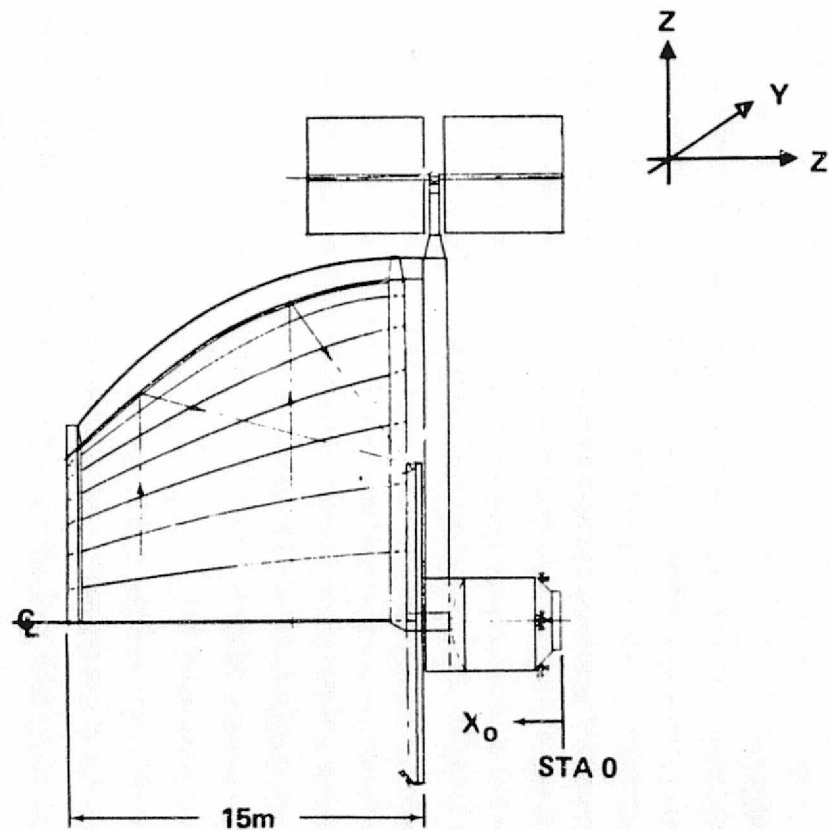
WEIGHT (KG)	15,400
BUS POWER (KW)	2.0
PANEL POWER (KW)	4.8
SOLAR PANEL AREA (m <sup>2</sup> )	45.5
BATTERY CAPACITY (AHR)	140
HUB DIAMETER (m)	4.3
HUB LENGTH (m)	6.2
STABILITY (DEG)	± 0.00015
SWATH WIDTH (KM)	1.16



MECHANICALLY SCANNED RADIOMETER

Figure 2.3.1-2. 30-Meter Radiometry Satellite

ITEM	MASS (kg)
ANTENNA SHELL	5,816
STRUCTURE	4,404
WHEEL AND COUNTERBALANCE	2,347
SOLAR PANELS	210
CONTROL MODULE	2,646
<b>TOTAL:</b>	<b>15,423</b>



MASS (kg)	CG (METERS)			MOMENT OF INERTIA		
15,423 kg (34,000 lb)	X	Z	Y	ROLL	YAW	PITCH
	9.4	6.1	0	1.60	1.03	1.68
	(kg x m <sup>2</sup> x 10 <sup>6</sup> )					

Figure 2.3.1-3. Mechanically Scanned 30-Meter Radiometer Mass Properties

using core-to-facing adhesive in a cocuring fixture. This assembly will then be press-cured.

The completed antenna segments, subsystem housing, and assemblies that protrude from the satellite such as the solar array, thruster modules, and communication antennas will be packaged for shipment to the SCB. Approximately 1-1/2 Shuttle launches will be required for transfer to orbit.

The guidance and control subsystem performance has been sized for attitude pointing of 0.5 to 5 arc-sec and a radiometer positioning accuracy of 3 to 10 m, resulting in a beam position accuracy at the earth's surface of  $\pm 2$  to  $\pm 20$  m. This corresponds to a 10% beam diameter uncertainty at the highest frequency of interest. To provide this performance, a power level of 870 W, a mass of 960 kg exclusive of the reaction control system, and a volume of  $1.57 \text{ m}^3$  are required. Thrusters have been sized at 50 to 100 N-sec, and a total impulse of 16 to  $160 \times 10^6$  N-sec is required between 3-year resupply periods. A propellant mass of 7,000 to 70,000 kg is also required. These ranges result from the uncertainty in operational altitude.

During testing, it is intended that a small subsatellite (565 kg) be used to provide an on-orbit "antenna test range." It will contain low-power emitters at either end of the frequency band sufficient to ascertain radiometer and antenna pattern performance and observe any anomalies due to frequency effects. The subsatellite will have a range of 185 km, a volume of  $1.66 \text{ m}^3$ , and require 168 kg of propellant (launch weight equals 733 kg). In addition, a subsatellite control console will be required with a volume of  $0.135 \text{ m}^3$  and mass of 45 kg, together with a 250-kg launcher and a launcher control unit with a volume of  $0.01 \text{ m}^3$  and mass of 12 kg.

It is expected that an existing unmanned satellite can be adapted to be a suitable carrier vehicle for the subsatellite. In particular, communications satellites generally have both the propulsion and command and control capabilities required. Another leading candidate is the Multimission Modular Spacecraft (MMS) currently in development by NASA. The MMS has a distinct advantage in that it is designed to be retrieved, refurbished, and relaunched by the Space Shuttle.

To support the checkout and test of the radiometry satellite, a subsystem console, alignment equipment, and data reduction/processing services will be required. Volume and mass of the test equipment are 3 m<sup>3</sup> and 100 kg. Data processing is expected to be performed by the SCB data facility.

#### 2.3.1.3 Activity and Test Descriptions

The objective of assembling the 30-m radiometer on-orbit is to conduct research and development work on the assembly of large antennas (to 600 m diameter) in space while producing a developmental satellite which will return earth resources data having a resolution nearly an order of magnitude greater than any other satellite. The 30-m radiometer antenna represents a break point for deployable antennas that can be fabricated with allowable surface error tolerances using conventional materials. It is also sufficiently large to provide insight into the problems of handling, assembling, and testing large-scale components on-orbit, and to serve most of the planned microwave scanning applications and frequencies.

The antenna and satellite will be assembled after the radiometer construction fixture and the EVA work stations are deployed and checked out. The radiometer satellite assembly sequence, taking into account the required EVA, is shown in Figure 2.3.1-4. The time required for each assembly activity is based on having 3 men each working a 10-hour shift. (Only 2 of the 3 men will be working at any given time at EVA).

Figure 2.3.1-5 illustrates the use of the construction fixture. An indexing table mounted on a deployable pallet allows the work to be rotated to within reach of the crane. One arm of the crane, equipped with an end effector, is employed in positioning the antenna frames, panels, and other equipment. The second arm holds an EVA work station, allowing the crew to visually guide component placement and install joining hardware.

The radiometer will be checked out by connecting subsystems to a checkout console via "drag-in" cables, and by evaluating system operability through a test program. Subsystems will be commanded to turn on in sequence and their interfaces and operations verified individually. An "all-systems" test will then be conducted. The operation of the radiometry equipment will be verified by commanding the system to return calibration data from emissive

- 2 RECEIVE/BERTH CARGO MODULE 1 (SATELLITE BODY, TURNTABLE, ELECTRONICS)
- 2 RECEIVE/BERTH CARGO MODULE 2 (ANTENNA PANELS, STRUCTURE)
- 3 INSTALL WORK STATIONS, LIGHTS; POSITION CRANE
- 0.5 INSTALL SATELLITE BODY ON TURNTABLE
- 6 INSTALL FRAMES AND BEAMS AND ALIGN
- 6 INSTALL PANELS AND ALIGN
- 3 INSTALL/ASSEMBLE WHEEL ASSEMBLY
- 6 INSTALL SECONDARY MIRRORS AND FEEDS
- 12 ALIGN MIRRORS AND FEEDS
- 12 INSTALL RADIOMETERS/ELECTRONIC EQUIPMENT
- 2 INSTALL SOLAR ARRAY MAST AND PANELS
- 5 INSTALL THRUSTERS COMM ANTENNA, ETC.

TOTAL TIME: 59.5 3-MAN SHIFTS

Figure 2.3.1-4. Radiometer Assembly Sequence



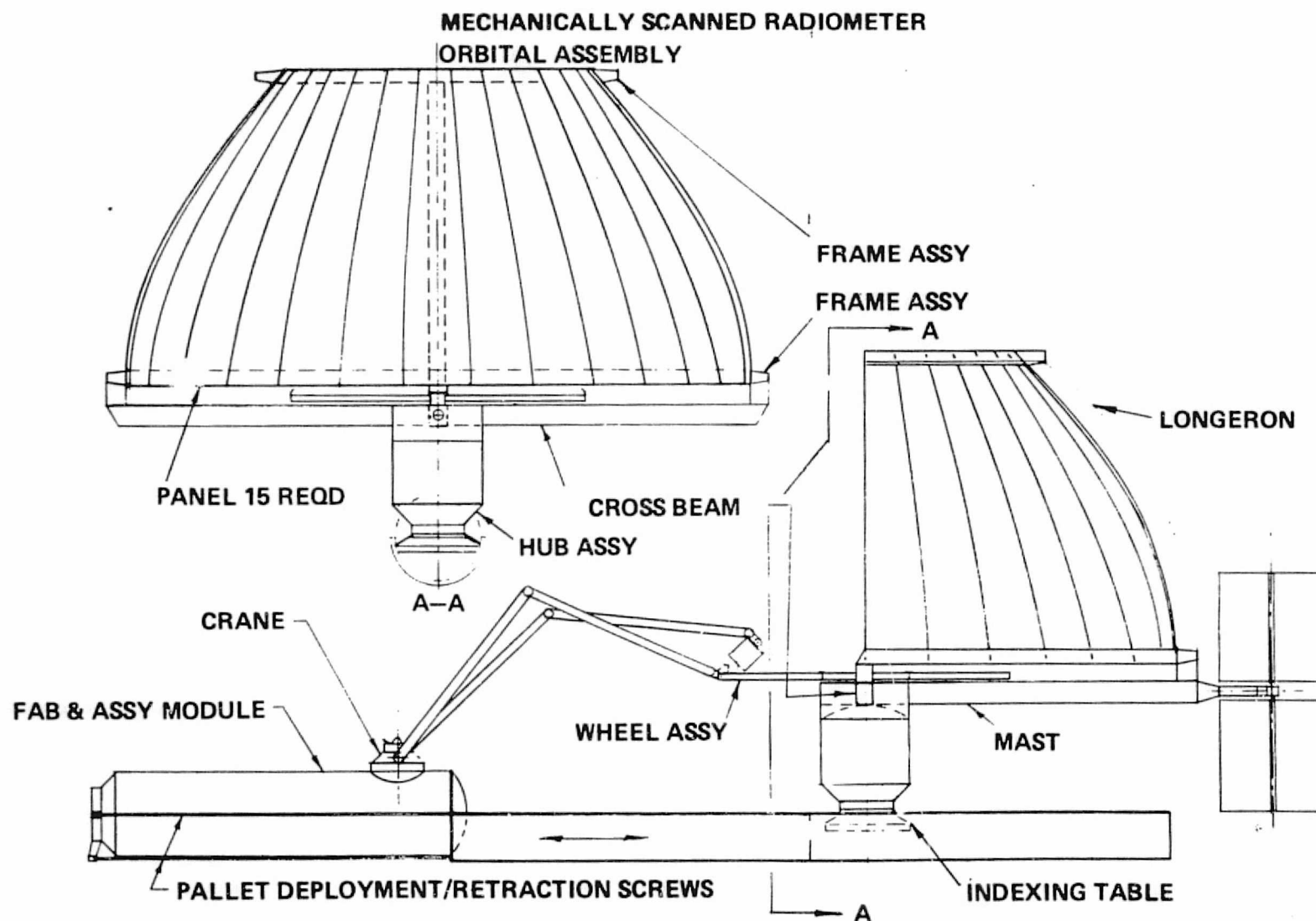


Figure 2.3.1-5. Construction Fixture 30-Meter Torus Radiometer Satellite

sources located on either antenna edges. These data will then be reduced and compared with desired levels to ensure that radiation integration times and data processing functions are producing brightness temperatures within design specifications.

The following tests will be conducted:

- A. Measure antenna surface deviation from parabolic contour to establish that the deviation does not exceed the error tolerance of 0.13 cm.
- B. Determine that natural frequency of structure is above control/response frequencies.
- C. Measure radiation pattern and contour deviation from circle (magnitude of sidelobes, pattern aberrations).
- D. Operate all subsystems and determine that their performance is in accord with specifications.
- E. Evaluate correlation of programmed microwave emissive amplitudes with data provided by radiometer.

Antenna deviation from the desired contour (Test A above) will be measured by placing a reflector at various locations on the surface and observing the angular dispersion between transmitted and reflected laser beams. This operation has been scheduled to follow structural response testing to ensure that any surface irregularities resulting from removal of accelerometers after structural tests are identified and smoothed. After mapping the readings, contours will be automatically plotted and the rms deviation calculated by computer.

The structural response tests (Test B) will require the mounting of accelerometers at various stations on the antenna panels. After their installation, vibratory forces will be coupled into the structure via hydraulic actuators and the antenna response observed. The natural frequency of the structure and harmonic modes will be determined by increases in accelerometer output.

The radiometer performance (Tests C, D, and E) will be determined using a subsatellite fitted out as an emissive source. At a range of 185 km, the subsatellite will transmit low-power signals at upper and lower frequency bands.

Its position with respect to the radiometer antenna will then be varied and the received signal strength at the radiometer will be recorded. Contours of relative signal level will then be plotted by computer. In addition, data processing programs will operate on the received signals and the performance of the programs will be evaluated. Adjustments to feed-horn alignment and system controls will be made as required, and the tests repeated until performance is satisfactory.

The test program schedule, shown in Figure 2.3.1-6, requires 34 shifts, with 2 men working the first 16 shifts and 1 man the subsequent 18 shifts. With the 59.5 three-man shifts needed for assembly, this results in a total of 93.5 shifts to complete the mission. Upon completion of the test program, the radiometer will be removed from the construction fixture and mounted on the OTV which will transport it to the desired operating inclination and altitude. Upon insertion into the desired orbit, it will be turned over to the agency responsible for its operational application.

#### 2.3.1.4 Space Construction Base Requirements

The requirements imposed upon the SCB to assemble, check out, and test the 30-m radiometer are given in this section.

##### Special Devices

An airlock is required which is capable of accommodating three persons, a crew of two in transfer to and from EVA plus an additional person, if necessary, to assist the crew in preparing for or returning from EVA. The required airlock volume is  $10 \text{ m}^3$ , providing for pressurization/depressurization, EVA equipment charge/recharge, cooling, equipment checkout and donning, emergency breathing support, and denitrogenation.

For EVA stowage and maintenance, a volume of  $10 \text{ m}^3$  is required. This volume will provide space for drying, stowing, and repairing space suits; two extravehicular mobile units; refueling and repair facilities for these units, and temporary stowage of tools and equipment.

A two-armed crane will be required which has a 20-m reach and is able to manipulate a 16-kg mass. Seven degrees of freedom will be required to permit motion of the crane body (yaw), shoulder joint (pitch and yaw), elbow

OPERATIONS

SUBSYSTEM  
CHECKOUT

STRUCTURAL  
RESPONSE

SURFACE  
ERROR

SATELLITE  
CHECKOUT

PATTERN  
MEASUREMENT

DATA  
DEVELOPMENT

DATA EVALUATION

ALIGNMENT/  
ADJUSTMENT

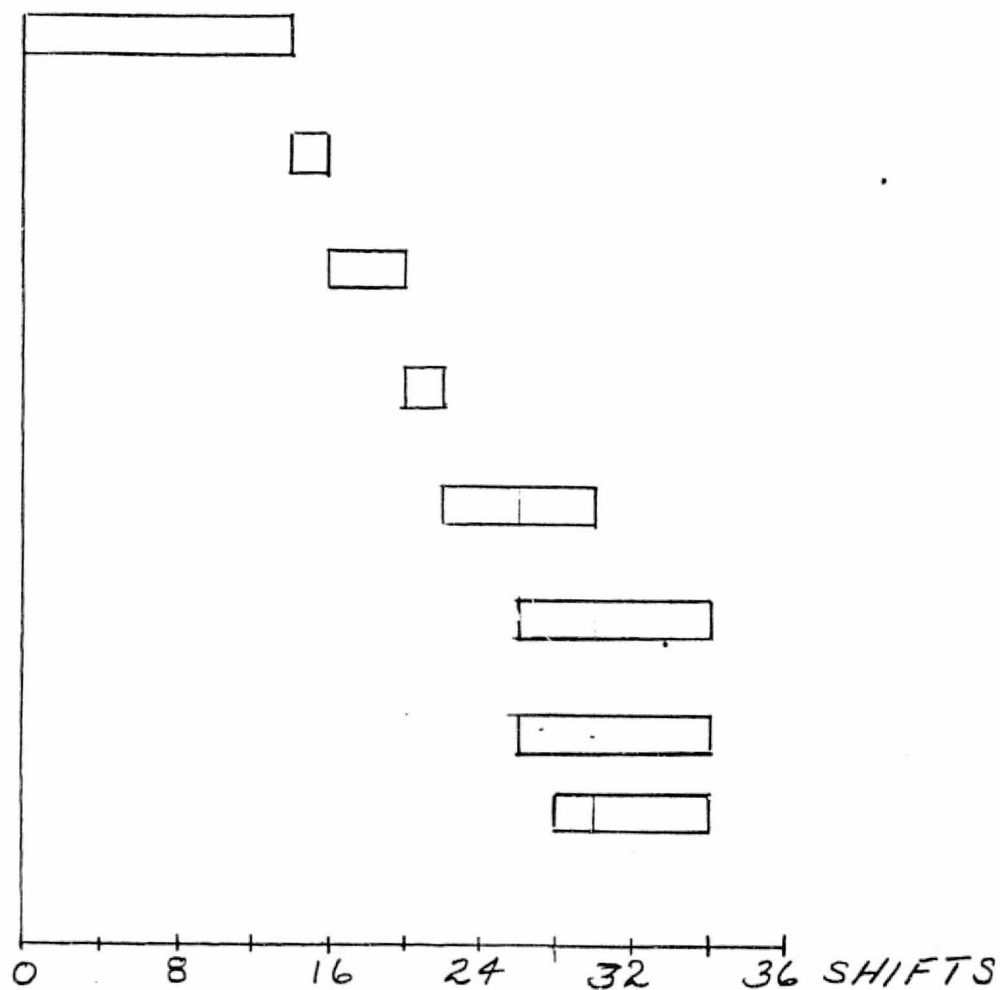


Figure 2.3.1-6. Test Program Schedule

(pitch), and wrist (pitch, yaw, and roll). The design must provide for both joint and independent crane arm control. The crane will need to be designed with an automatic collision avoidance feature, have a 4-cm end effector positioning capability, and be equipped with TV cameras that can "zoom" and have automatic light control.

The assembly fixture must be at least 16 m long and 5 m wide. A hub is required at the end of the fixture which can rotate 360 deg. The hub should contain provisions for attachment of the satellite body. The fixture must also have controls for indexing the hub to the desired position.

The EVA work station must allow freedom of movement for two crewmen and must have provisions for tethers and constraints and for storage of tools and components. The station must also allow the attachment of fittings to the crane wrist.

#### Personnel

Six skill categories will be required. A maximum of 3 men will be working at any one time. The specialties required and the shifts worked by each man are given below:

- |           |  |
|-----------|--|
| Assembly: | 1 crane operator<br>2 EVA construction personnel                         |
|           | • 59.5 shifts  |
| Checkout: | 1 electronics specialist<br>1 mechanical specialist                      |
|           | • 16 shifts  |
| Test:     | 1 radiometry specialist experienced in<br>radiometry and antenna testing |
|           | • 18 shifts  |

It is assumed that a data processing specialist is available for support, although his time is not included in the above figures.

#### Volume

A pressurized volume of 35 m<sup>3</sup> will be required. The following volumes have been allocated for the following items:

Crane Control Station - 0.2 m<sup>3</sup>

Radiometer-OTV Control Station - 0.135 m<sup>3</sup>

Radiometer Checkout Console —  $1.2 \text{ m}^3$   
Subsatellite Maintenance Bench —  $2 \text{ m}^3$   
Subsatellite Launcher Control Unit —  $0.01 \text{ m}^3$   
Alignment and Test Equipment Stowage —  $3 \text{ m}^3$   
Tool Stowage —  $2 \text{ m}^3$   
Data Processing —  $4 \text{ m}^3$   
Miscellaneous —  $1.5 \text{ m}^3$

The remaining  $20 \text{ m}^3$  is free volume.

#### Berthing

Berthing ports for pallets with an unpressurized volume of  $392 \text{ m}^3$  are required to house the radiometer components prior to assembly. A berthing port (or comparable rigid attachment to the SCB or assembly fixture) is also required for the OTV during mating operations with the radiometer.

#### Mass

The SCB must be able to maintain orientation and stability requirements with an attached mass of 15,423 kg for the radiometer.

A mass of 1700 kg will be required for support equipment. It has been allocated as follows for the following items:

Crane Control Station — 60 kg  
Radiometer-OTV Control Station — 45 kg  
Radiometer Checkout Console — 200 kg  
Subsatellite Maintenance Bench — 400 kg  
Subsatellite Launcher Control Unit — 12 kg  
Alignment and Test Equipment — 25 kg  
Tool Stowage — 75 kg  
Data Processing — 150 kg  
Subsatellite — 733 kg

#### Power

The average power required will be 2000 W, with a peak power load of 4000 W, 1275 W of which will be allocated to lighting during orbital dark periods of 36 minutes.

### Illumination

A minimum of 20% of the antenna surface will be illuminated at any given time with a brightness of 200 Lumens/m<sup>2</sup>.

### Data and Communications

The data rate required for unprocessed data is 169 Mbps and for compressed data, 17 Mbps. An image memory of  $2 \times 10^9$  bits is required (one frame  $\approx 800 \times 800$  km).

### 2.3.2 Multi-Beam Lens Antenna

#### 2.3.2.1 Mission Overview

This active communications repeater is an automated satellite for multi-channel, point-to-point transmission of high-rate data.

The device is designed for electronic mail delivery between post offices in the Continental US. Each post office would automatically encode written material and transmit it to the multi-beam lens antenna in geostationary orbit using a 1-m fixed antenna mounted on the post office roof. The satellite would receive the encoded data and retransmit them to the appropriate post office for delivery to the addressee. The system would result in more rapid mail transfer and distribution and reduce the number of manual mail-handling tasks required with existing facilities.

While the intent is to provide an operational system specifically for use in the postal service, the unique characteristics of the antenna make it suitable for other applications. For example, a system of the same general type, but with markedly different characteristics, could be developed to provide a personal communications system that would supply a voice link between individuals in the Continental US. Accordingly, this mission should also establish the methods, hardware, and support equipment needed to produce systems of this general type and to verify their cost-effectiveness.

#### 2.3.2.2 Mission Hardware Description

The satellite provides for transmitting and receiving multiple beams by focusing energy from and to a primary array of feed horns through a microwave lens. The ray paths through the lens are constrained to follow RF

transmission lines connecting small pickup and reradiating elements. The lens has a spherical inner surface and a planar outer surface with equal-length delay lines.

This satellite is to operate at the X or K band in the 8 to 10 GHz range and provide bandwidths of 1000 MHz for reception and transmission. One thousand beams will be required for coverage of post offices within the Continental U.S. These require a power of 5 to 10 W per beam. Beam widths of 0.1 degree on centers will be provided and a frequency reuse technique will be employed. Beam-to-beam isolation of 25 db will be required with sidelobes greater than 30 db down from the main beams. The multi-beam lens antenna performance requirements also include a gain temperature ratio of 30 db/ K and an effective isotropic radiated power of 94.7 dbW.

Based upon these specifications, a design was prepared with the physical characteristics shown in Figure 2.3.2-1. It is evident that both the mass and power requirements are quite large. The mass properties for the satellite, which are shown in Figure 2.3.2-2, result from the use of graphite/epoxy material in its construction. The power requirements result from the potential need to transmit data simultaneously to all post offices plus an allowance for subsystem operation. At synchronous orbit, since the satellite will operate continuously in sunlight (with the exception of brief periods during the equinoxes), solar array area requirements are nominal; i. e., battery charging is virtually eliminated.

The stability and control system requirements are nominal and may be met by conventional reaction wheel and thruster components. The system would consume 100 W of power, have a mass of 450 kg (exclusive of propellant) and a volume of  $0.3 \text{ m}^3$ . Assuming a 7-year resupply time, an impulse of  $9.3 \times 10^6 \text{ N-sec}$  would be required, provided by hydrazine propellant with a mass of 4100 kg and tankage of  $4.2 \text{ m}^3$ .

The antenna, illustrated in Figure 2.3.2-3, consists of a transverse electromagnetic mode lens-type structure with a focal length of 26.5 m, a lens thickness of 0.61 m at its center, and a maximum delay line length at the lens periphery of 4.16 m. The lens dimensions result from the concave



## CHARACTERISTICS

WEIGHT (KG)	29K
BUSS POWER (KW)	16.7K
PANEL POWER (KW)	19.6K
SOLAR PANEL AREA (m <sup>2</sup> )	186
STABILITY (DEG)	$\pm 0.005$
MODULE DIAMETER (m)	3.66
MODULE LENGTH (m)	4
LENS THICKNESS (CENTER) (m)	0.061
(PERIPHERY) (m)	4.2

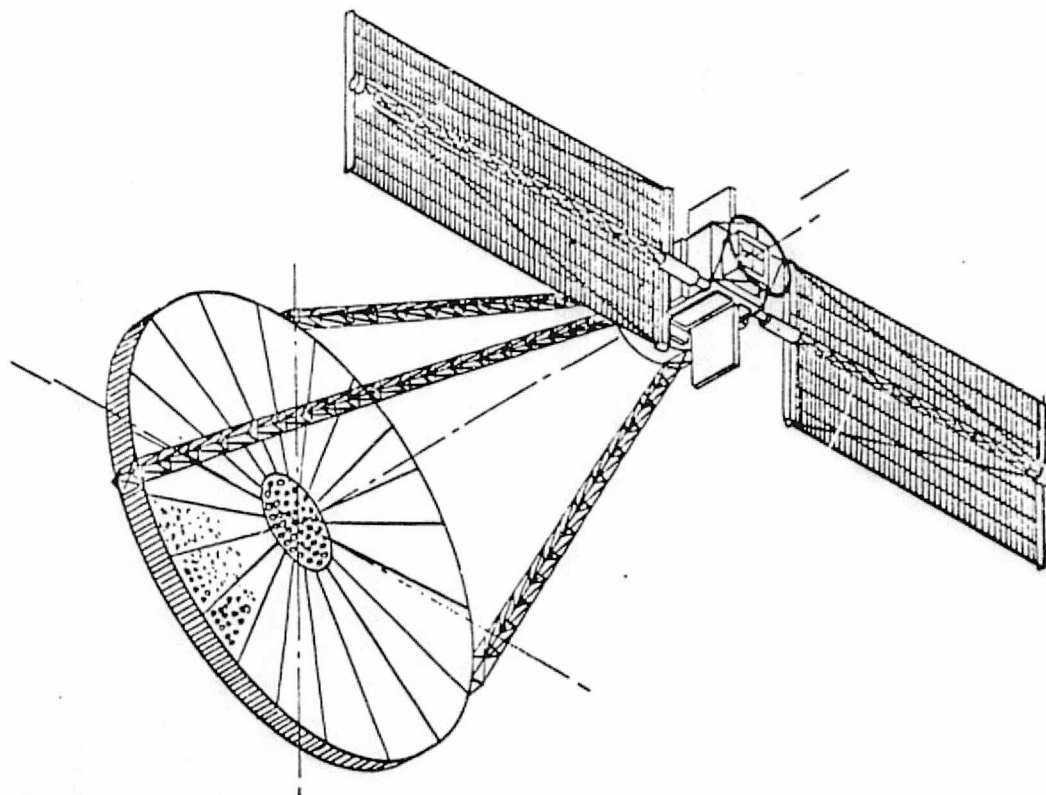
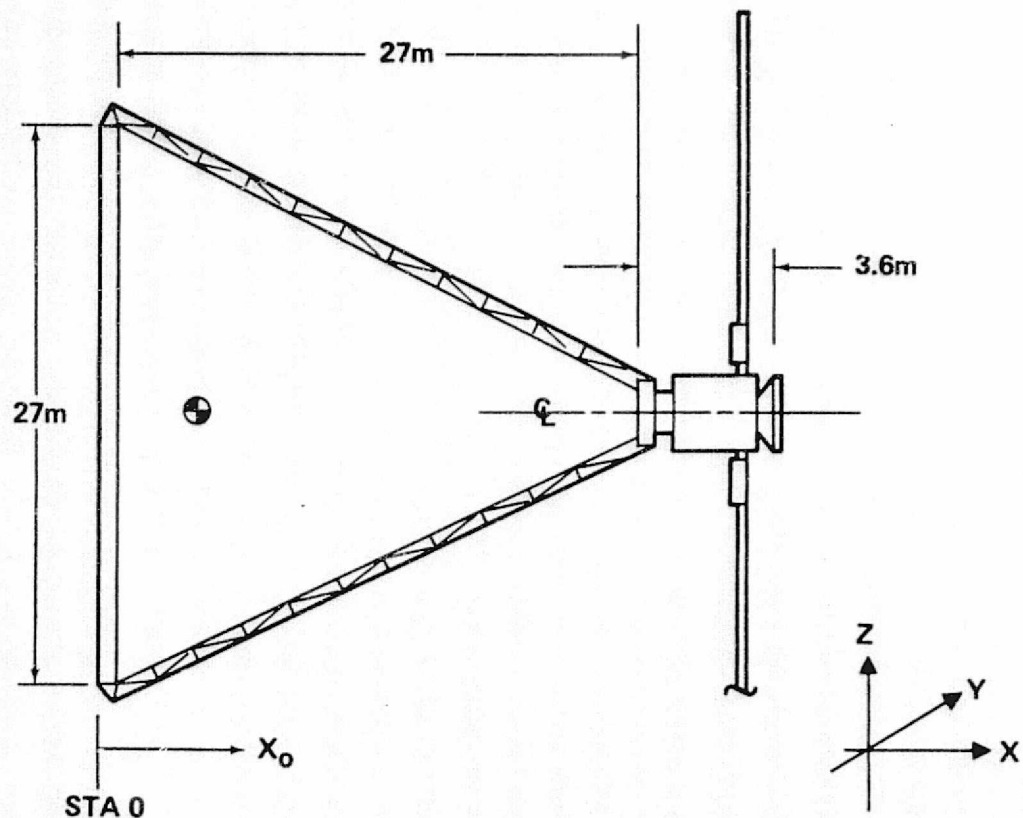


Figure 2.3.2-1. 27m Multibeam Lens Satellite

ITEM	MASS (kg)
LENS	26,650
TRUSS BEAMS	835
FEEDER ARRAY	231
SOLAR PANELS	635
CONTROL MODULE	1,452
<b>TOTAL:</b>	<b>29,083</b>



**MASS**  
29,083 kg (65,700 lb)

**CG (METERS)**

X	Z	Y
2.9	0	0

**MOMENT OF INERTIA**

ROLL	YAW	PITCH
2.60	3.14	3.25
(kg - m <sup>2</sup> x 10 <sup>6</sup> )		

Figure 2.3.2-2. Multibeam Lens Antenna Mass Properties

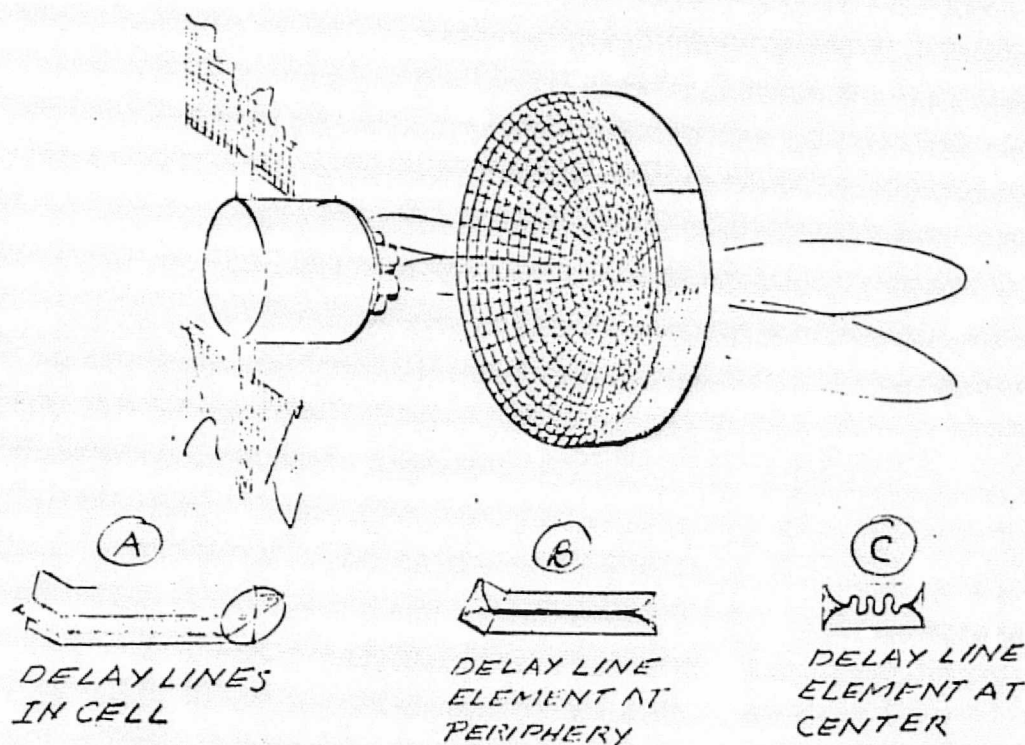


Figure 2.3.2-3. Antenna Lens and Feed Configuration

spherical shape of the inner surface which requires a minimum 3.5-m length delay line at the edge ((B) in the figure) to connect the inner array elements to the retransmit elements on the outer planar surface and the smallest distance at the lens center into which an equal delay line length ((C) in the figure) can be packaged. The microstrip delay lines ((A) in the figure), with radiators (horns) at either end, are photo-etched on the two sides of a flat, copper-clad dielectric card. Each card is mated with a second orthogonal card in a cross configuration and placed in a cell. 600,000 radiator cells, contained in the 700-wavelength (26.5m)-diameter lens, are driven by 1000 feed horns. The diameter of the feed array is 3.05 m while the diameter of each horn is 4.57 cm.

To support antenna tests in low-earth orbit, a small subsatellite (565 kg) will be employed as an on-orbit "test range." It will contain beam mapping transmitters and receivers. By relative position changes and signal strength measurements, it will be able to define the patterns formed by the antenna and determine that power, beam isolation, and sidelobe levels have been met.

The subsatellite will have a range of 185 km, a volume of  $1.6 \text{ m}^3$ , and require 168 kg of propellant (launch weight equals 733 kg). In addition, a control console with a volume of  $0.135 \text{ m}^3$  and a mass of 45 kg will be required, together with a 250-kg launcher and launch control unit with a volume of  $0.01 \text{ m}^3$  and a mass of 12 kg.

It is expected that an existing unmanned satellite can be adapted to be a suitable carrier vehicle for the subsatellite. In particular, communications satellites generally have both the propulsion and command and control capabilities required. Another leading candidate is the Multimission Modular Spacecraft (MMS) currently in development by NASA. The MMS has a distinct advantage in that it is designed to be retrieved, refurbished, and relaunched by the Space Shuttle.

To support the checkout and test of the antenna, a dedicated subsystem console including RF test equipment will be required. Volume and mass of this console are  $5 \text{ m}^3$  and 150 kg.

#### 2.3.2.3 Activity and Test Descriptions

A communications satellite employing a multi-beam lens will be assembled on-orbit to provide data transfer between post offices in the United States. The capability will be provided in one satellite for data reception, routing, and transmission which would normally require many satellites. Further, the size and complexity of the ground mail stations can be reduced by increasing the performance of the on-orbit segment of the communications system.

The subsystem module and the antenna will be fabricated on the ground. The antenna will be constructed from GY70 graphite epoxy tubes (forming the individual radiating element cells) bonded together to form antenna sections that will be joined in space. An outer diameter closeout/attach ring, molded in segments, will then be attached to the periphery of the sections.

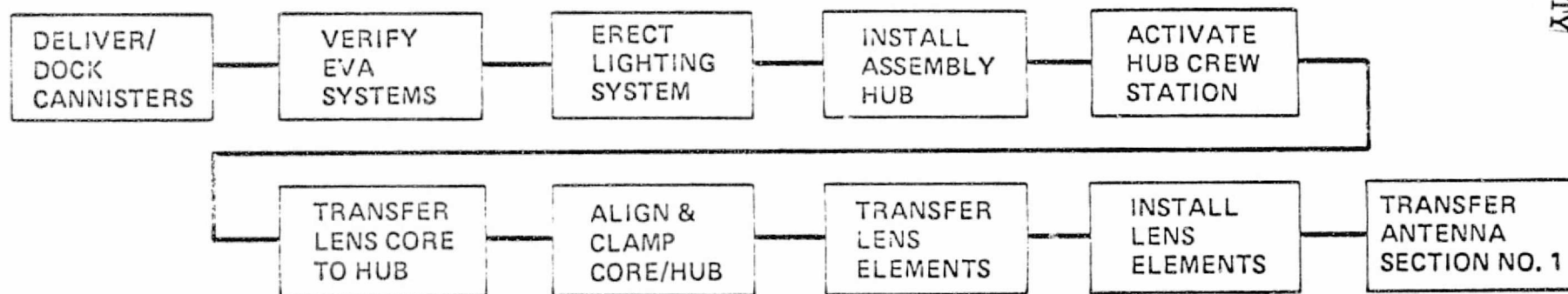
The antenna support trusses (beams) joining the module to the antenna will be fabricated from the same type of graphite fiber in view of the requirements for a low coefficient of expansion and high stiffness. The required textile form will be a continuous fiber yarn or roving (untwisted material in yarn form) because of the contemplated manufacturing process for truss members. The antenna trusses could be fabricated on the ground or on-orbit. The antenna, together with the other satellite subassemblies, will be packaged for shipment and transported to the Space Construction Base (SCB). The satellite will then be assembled on-orbit. Approximately three shuttle launches will be required.

Assembly operations for the multi-beam lens antenna and satellite are illustrated in Figure 2.3.2-4. After installation of a rotating hub assembly and support equipment such as lighting fixtures, the central lens core will be attached to the hub. To prevent breakage, the core lens elements will not be installed until after all sections have been attached. Outer sections of the lens, in which lens elements have already been placed, will then be attached to the core. The hub will be rotated 18 degrees after joining each section to allow the joining operation to occur at the same relative work position. With all sections in place, the outer close-out and attach ring will be installed. The satellite support struts will then be positioned and attached to this ring. A second ring, forming the mounting base for the satellite module, will be attached to the other end of the struts. The module will then be joined to the ring and the external subsystem assemblies such as thrusters and solar panels will be fitted.

The timetable for assembly operations is shown in Figure 2.3.2-5. The 54 shifts indicated assume three men per shift.

After the satellite is completed, the crane will be used to reverse its position so that the satellite module is attached to the station in order to simplify testing and adjustment. Test cables and instrumentation will then be connected to the satellite module and subsystem checkout performed. The primary objective of the checkout process will be to ensure that all subsystems perform within allowable tolerances and that mating operations have been properly

(Text continued on page 181)



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INSTALL/ACTIVATE  
SUPPORT EQUIPMENT

ATTACH ANTENNA  
CORE TO HUB

INSTALL LENS  
ELEMENTS

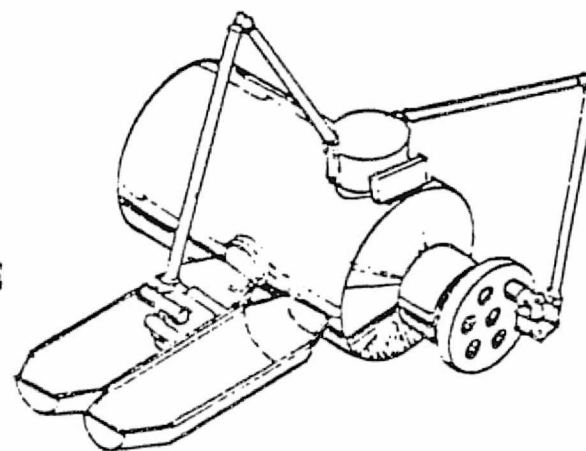
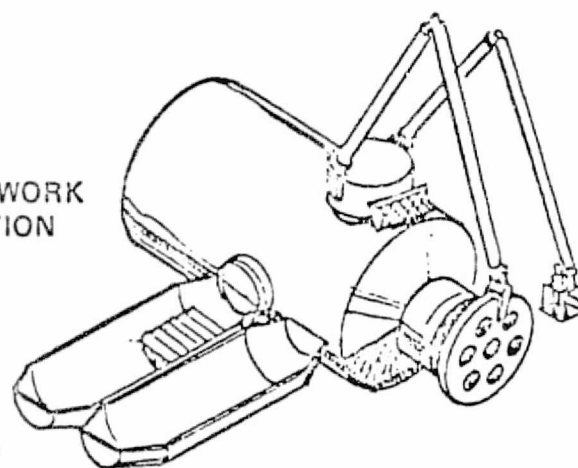
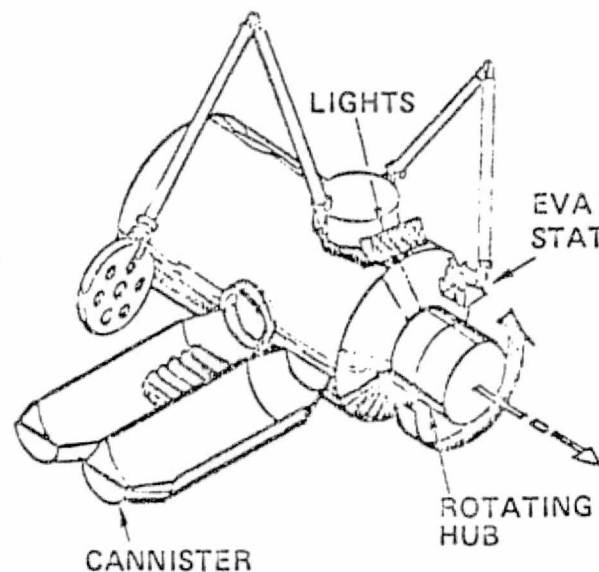
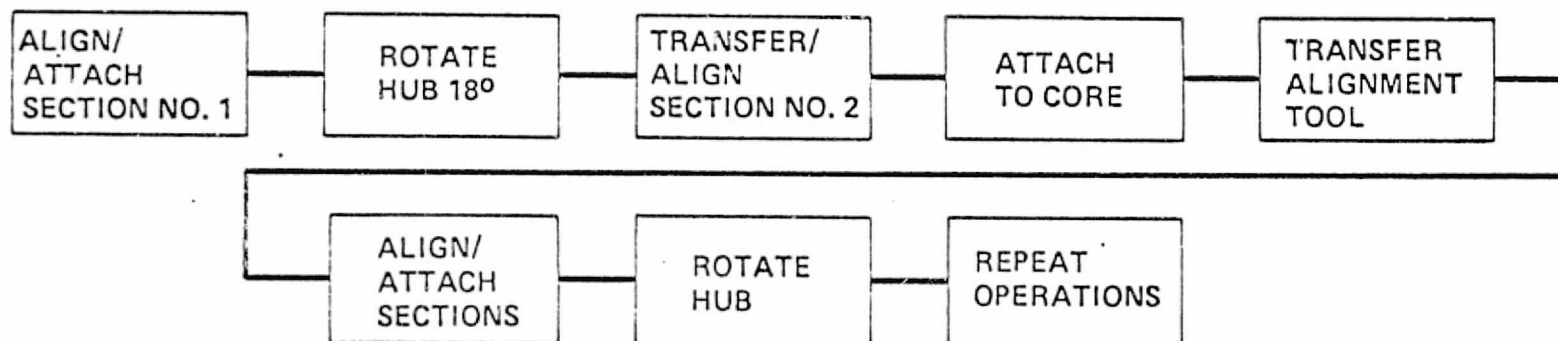
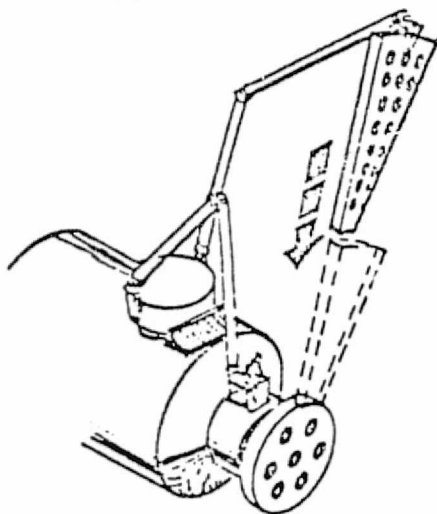


Figure 2.3.2-4. Multibeam Lens Satellite Assembly Sequence No. 1 (Page 1 of 4)

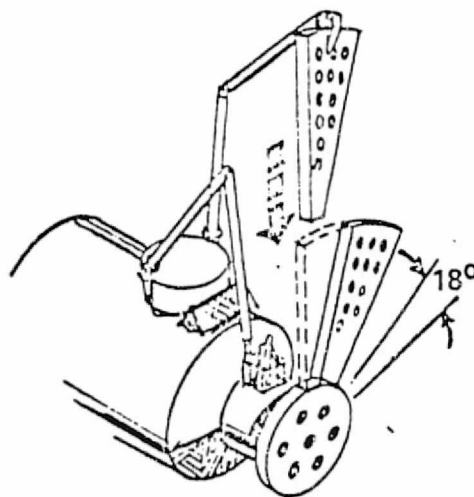




ATTACH SECTION  
NO. 1



ATTACH SECTION  
NO. 2



INSTALL ALIGNMENT  
TOOLS

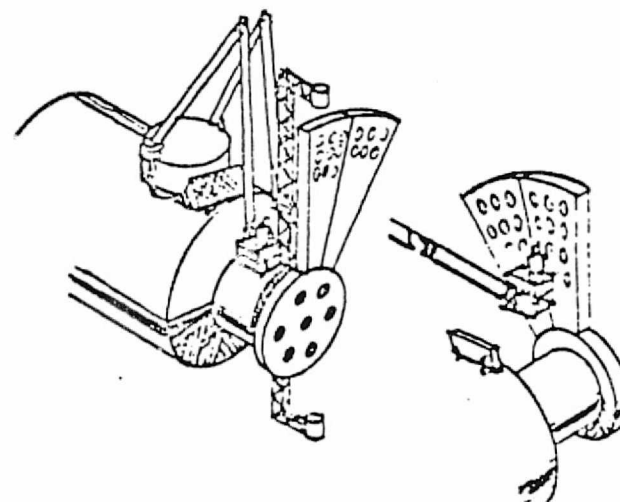
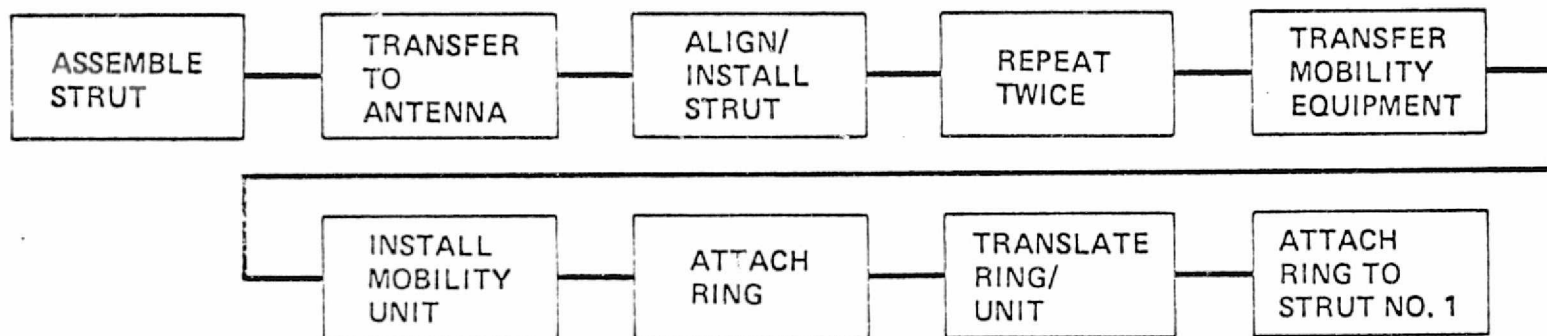
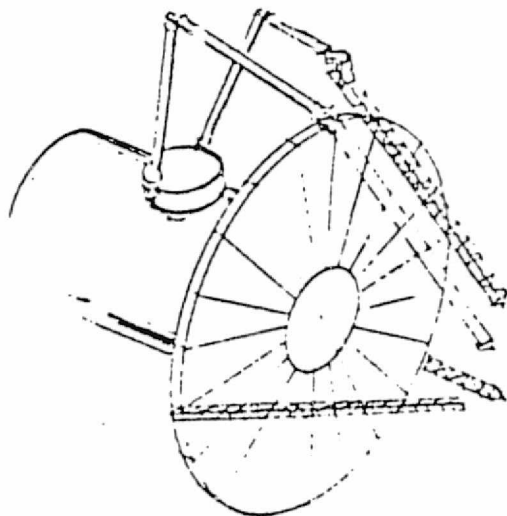


Figure 2.3.2-4. Multibeam Lens Satellite Assembly Sequence No. 2 (Page 2 of 4)

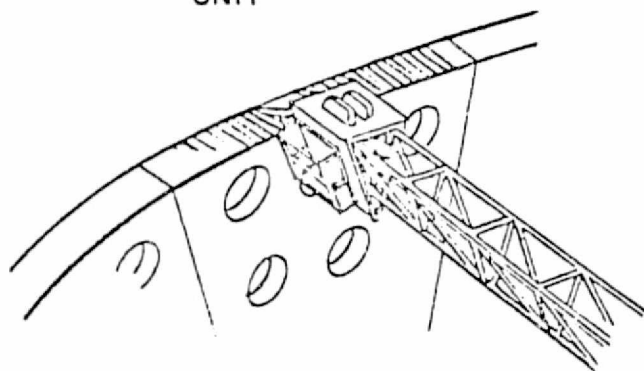


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INSTALL STRUTS



INSTALL MOBILITY UNIT



ATTACH RING

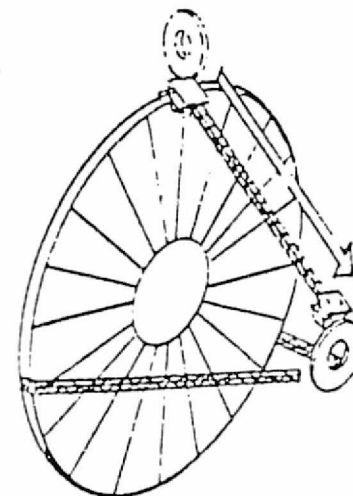
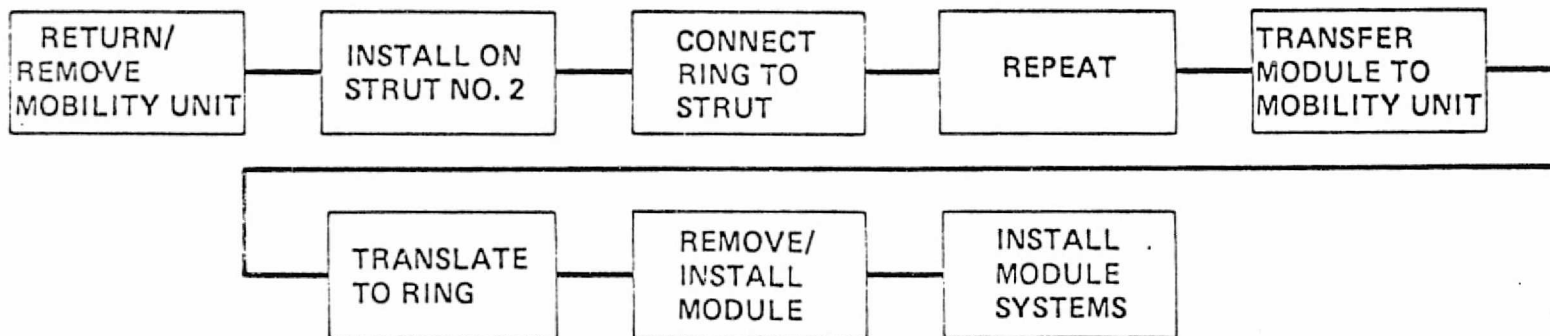
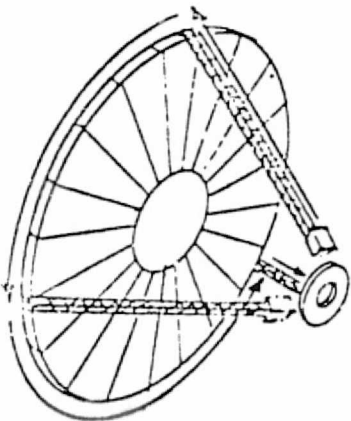


Figure 2.3.2-4. Multibeam Lens Satellite Assembly Sequence No. 3 (Page 3 of 4)

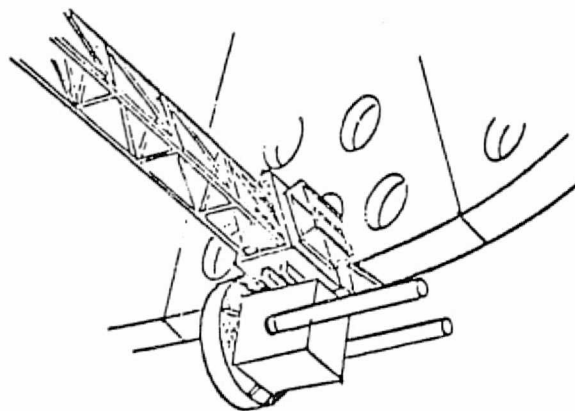




MOBILITY UNIT  
MOVES FROM STRUT  
TO STRUT



TRANSFER OF SATELLITE  
MODULE TO RING



MODULE  
INSTALLATION

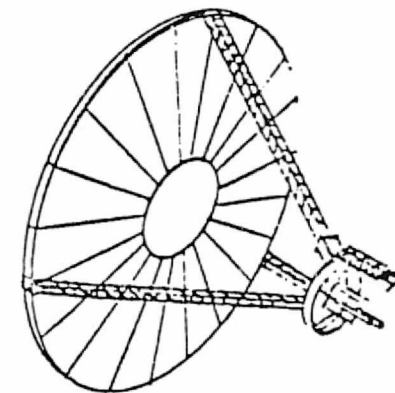


Figure 2.3.2-4. Multibeam Lens Satellite Assembly Sequence No. 4 (Page 4 of 4)

(3)\* DELIVER FIRST CARGO MODULE (INCLUDES MAXIMUM ALLOWANCES FOR LAUNCH, ASCENT, BERTHING, DEORBING, AND LANDING)

(15) ORBITER TURNAROUND

(3) DELIVER SECOND CARGO MODULE

(15) ORBITER TURNAROUND

(3) DELIVER THIRD MODULE

(2) INSTALL SATELLITE ASSEMBLY TOOLS

(10) ASSEMBLE TEM LENS

(2) ALIGN COMPLETED ASSEMBLY

(27) INSTALL TEM LENS ELEMENTS (13,500)

(3) ASSEMBLE TRIPOD SUPPORT STRUCTURE & MODULE ATTACH RING

(2) JOIN SATELLITE MODULE

(3) INSTALL SOLAR ARRAYS

(5) INSTALL REMAINING ASSEMBLIES

\* DAYS ASSUMING SINGLE SHIFT OPERATIONS

• SATELLITE ASSEMBLY DELIVERY TO ORBIT = 39 DAYS

• SATELLITE ASSEMBLY = 54 DAYS

TEM = TRANSVERSE ELECTROMAGNETIC MODE

Figure 2.3.2-5. MBL Satellite Assembly

carried out. The multi-beam lens subsystems will be connected to a test console in the SCB. Each subsystem will then be sequentially activated and its performance ascertained either by issuing commands or by inserting stimuli. Recorded test data will be evaluated by comparison with predetermined performance criteria using SCB data-processing facilities.

After the subsystem and all-system tests have been conducted, two subsatellites will be launched and positioned in the antenna far-field at a range of approximately 185 km. Pattern measurements will then be obtained by transmitting an RF signal with an axial beam and moving the satellite relative to the beam axis. Signal strength measurements will be transmitted back to the SCB, stored in the computer until sufficient samples have been obtained, and a printout then made of relative intensity. Similar test runs will be made with the beam offset. The degree of beam isolation will be indicated as a function of satellite position by operating the system with two or more beams being transmitted at different frequencies and measuring the signal level of one in respect to the other.

The gain/temperature ratio will be obtained by first measuring the gain using a normalized comparison technique that employs a normalizing attenuator and a standard gain horn. A signal will be transmitted from one of the subsatellites, received by the multi-beam lens antenna, reduced by a loss network, and a reference level reading obtained with a digital voltmeter.

The voltmeter will be preceded by an attenuator to provide a convenient reference level. The multi-beam lens receiver will then be switched to a standard gain horn with the loss network out of the circuit and a new reference reading obtained. The attenuator will then be adjusted until a reading corresponding to the first is obtained. The gain of the multi-beam lens will be the arithmetic sum of the standard gain horn gain, the loss network value, and the amount of change in the attenuator setting.

The noise temperature will be measured by first utilizing an accurately calibrated nitrogen cold load and room temperature load to measure receiver noise, then measuring the antenna temperature, and combining the two for total system temperature.

The final series of tests will employ both subsatellites, one simulating a transmitting post office and the other simulating the receiving post office. The data transmitted and received by the two subsatellites will be telemetered back to the SCB for comparison. The comparison, which will yield bit error rates, will be repeated using different subsatellite locations and signal levels.

The proposed schedule for the test program is shown in Figure 2.3.2-6. However, the actual time required for simulated operations will depend upon the number of problems encountered and the difficulty of the corrective action, especially in tests of modulation/demodulation equipment and the beam switching networks.

After any anomalies uncovered by the test program are corrected, the antenna will be fueled, mated with the OTV, and transferred to synchronous orbit. Upon insertion into the desired orbit, the multi-beam lens antenna will be turned over to the agency responsible for its operational application.

#### 2.3.2.4 Space Construction Base Requirements

The requirements imposed upon the SCB to assemble, check out, and test the multi-beam lens antenna are given in this section.

##### Special Devices

An airlock is required which is capable of accommodating three persons, including a crew of two in transfer to and from EVA plus an additional person, if necessary, to assist the crew in preparing for or returning from EVA. The required airlock volume is  $10 \text{ m}^3$ , providing for pressurization/depressurization, EVA equipment charge/recharge, cooling, equipment checkout and donning, emergency breathing support, and denitrogenation.

For EVA stowage and maintenance, a volume of  $10 \text{ m}^3$  is required. This volume will provide for drying, stowing, and repair of space suits; two extravehicular mobile units; refueling and repair facilities for these units, and temporary stowage of tools and equipment.

OPERATIONS

SUBSYSTEM  
CHECKOUT

PATTERN  
MEASUREMENT

BEAM ISOLATION

GAIN/TEMPERATURE  
RATIO

SIMULATED  
OPERATIONS

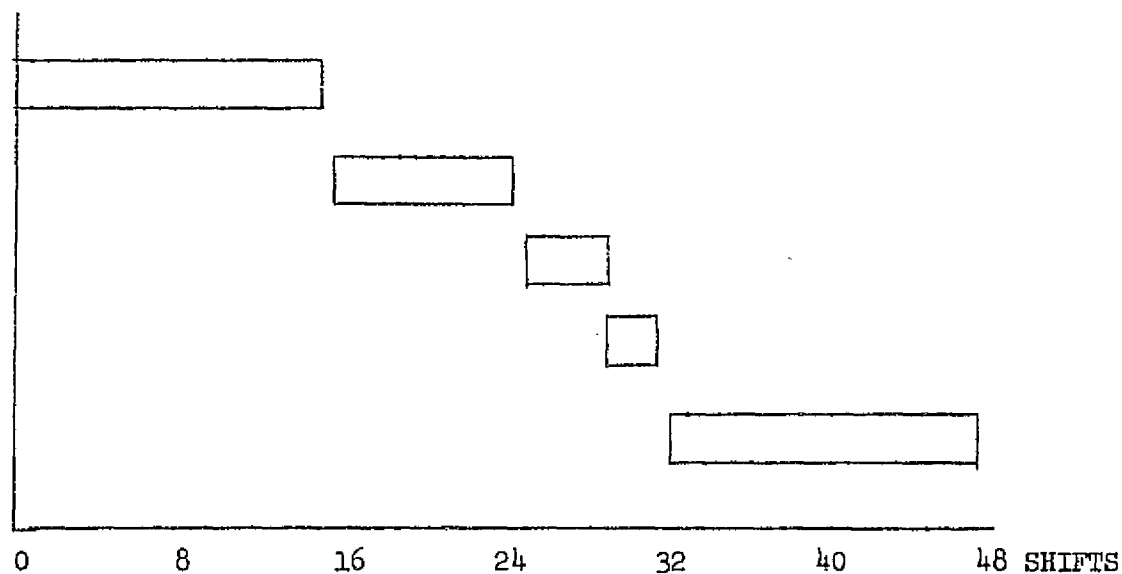


Figure 2.3.2-6. Test Program Schedule

ORIGINAL PAGE IS  
OF POOR QUALITY

### Volume

A pressurized volume of  $35 \text{ m}^3$  will be required. The volume has been allocated for the following items:

Crane Control Station —  $0.2 \text{ m}^3$

Satellite/OTV Control Station —  $0.135 \text{ m}^3$

Checkout Console (for power subsystem, guidance subsystems, and computer data management subsystem) —  $1.2 \text{ m}^3$

Subsatellite Maintenance Bench —  $2 \text{ m}^3$

Subsatellite Launcher Control Unit —  $0.01 \text{ m}^3$

Alignment/Test Equipment Stowage —  $3 \text{ m}^3$

Tool Stowage —  $2 \text{ m}^3$

Data Processing —  $4 \text{ m}^3$

Miscellaneous —  $1.5 \text{ m}^3$

The remaining  $20 \text{ m}^3$  is free volume.

### Berthing

Berthing ports for pallets with an unpressurized volume of  $666 \text{ m}^3$  are required to house the satellite components prior to assembly. A berthing port (or comparable rigid attachment to the SCB or construction fixture) is also required for the OTV during mating operations with the satellite.

### Mass

The SCB must be able to maintain orientation and stability requirements with an attached satellite mass of 29,000 kg.

A mass of 1800 kg will be required for support equipment. It has been allocated for the following items:

Crane Control Station	60 kg
Satellite/OTV Control Station	45 kg
Checkout Console	200 kg
Subsatellite Maintenance Bench	400 kg
Subsatellite Launcher Control Unit	12 kg
Alignment/Test Equipment	25 kg
Tool Stowage	75 kg
Data Processing	150 kg
Subsatellites (2)	1466 kg

A two-armed crane will be required which has a 16-m reach and is able to manipulate a 29,000-kg mass. Seven degrees of freedom will be required to permit motion of the crane body (yaw), shoulder joint (pitch and yaw), elbow (pitch), and wrist (pitch, yaw, and roll). The design must provide for both joint and independent crane arm control. The crane will need to be designed with an automatic collision avoidance feature, have a 4-cm end effector positioning capability, and be equipped with TV cameras that can "zoom" and have automatic light control.

The assembly fixture must be equipped with a hub at the end of the fixture which can rotate 360 degrees. The hub should contain provisions for attachment of the antenna core section. The fixture must also have controls for indexing the hub to the desired position.

The EVA work station must allow freedom of movement for two crewmen and must have provisions for tethers and constraints and for storage of tools and components. The station must also allow the attachment of fittings to the crane wrist.

#### Personnel

Seven different skill categories are required. A maximum of 3 men will be working at any one time. The specialties required and the shifts worked by each man are given below:

- |           |   |
|-----------|---|
| Assembly: | 1 crane operator,<br>2 EVA construction personnel<br>● 54 shifts    |
| Checkout: | 1 electronics specialist,<br>1 mechanical specialist<br>● 16 shifts |
| Test:     | 1 communications specialist<br>1 antenna specialist<br>● 32 shifts  |

It is assumed that a data processing specialist is available for support, although his time is not included in the above figures.

### Power

The average power required will be 2000 W, with a peak power load of 4000 W. 1275 W of this power will be allocated to lighting during orbital dark periods of 36 minutes.

### Illumination

A minimum of 20% of the antenna surface will be illuminated at any given time with a brightness of 200 lumens/m<sup>2</sup>.

### Data and Communications

The subsatellite tracking accuracy required is  $\pm 3.5$  m at a range of 185 km.

The bit rate required for commands is 1 kbps and for data, 1 Mbps.

### Stabilization

Attitude control is required during various stages of assembly. The required stability for operational tests in low-earth orbit is  $\pm 0.005$  degree in azimuth and elevation, with a maximum rate of 0.013 deg/sec.



## 2.4 MULTIDISCIPLINE SCIENCE LABORATORY

### 2.4.1 Mission Overview

The Multidiscipline Science Laboratory (MDSL) is the Objective Element which encompasses the next generation of basic space research activities. As such, it will capitalize on the unique attributes of space (weightlessness, lack of atmospheric attenuation, wide areal coverage, etc.) for accomplishing research in the following areas: (1) the effects of a micro-gravity environment on the basic physics, chemistry, and materials sciences; (2) earth sciences; (3) life sciences (including effects of micro-gravity on terrestrial life, and physiology and disease processes); (4) space sciences, and (5) applied research in support of other objectives. The initial research will provide the basis for the design of dedicated facilities for specialized activities such as sensor development, life sciences, astronomy support (solar and stellar), or planetary sample return.

### 2.4.2 Mission Hardware Description

The development of the MDSL is governed by the following ground rules:

- MDSL will operate concurrent with other objectives, simultaneously using support resources and a General Purpose Laboratory (GPL) on a compatible and minimum-interference basis.
- All basic operational support requirements (e.g., power, heat rejection, crew facilities, communications, and data management) will be provided by the Space Construction Base (SCB). Special requirements (e.g., cryogenic fluids or inert gases) will be part of the MDSL experiment.
- Research will be scheduled to avoid unreasonable combinations that result in excessive peak power loads.
- MDSL research will be conducted by government agencies, academic institutions, and commercial organizations.
- The GPL will be modular in concept and Shuttle-compatible.
- The GPL configuration will allow for hazardous experiments.
- Operations of the GPL will be organized similar to typical oceanographic research vessels; i.e., research crews will normally participate in SCB housekeeping operations or maintenance activities.

- Space research requiring very low acceleration disturbances will use a dedicated minimum disturbance module (floated table).

A representative GPL is illustrated in Figure 2.4-1. Figure 2.4-2 depicts specific research and support stations which might be installed in this laboratory module, and indicates the types of functions which would be performed at each station. Table 2.4-1 provides the primary equipment list for the GPL module shown in Figure 2.4-1.

As research demands increase and budgetary constraints permit, additional GPL modules may be delivered to orbit, or the existing orbital system may be refurbished and reconfigured to accommodate changing requirements. In certain areas (e.g., space sciences or earth observations), sensors will need to be mounted externally on an unpressurized pallet.

#### 2.4.3 Activities Description

The MDSL will include a broad range of research objectives. These research programs will have no unique sequence of activities except on a detailed sub-objective level. Typically, work on several subobjectives will be in process at one time. In fact, some research subobjectives such as solar physics and astronomical observations have no logically definable termination point.

Typical space research projects which will be conducted in the MDSL Objective Element are discussed in the following paragraphs.

#### Materials Science

One of the most severe problems encountered in research on terrestrial materials involves the crucible; specifically, contamination of the melt by the crucible walls. Various levitation schemes have sought to eliminate this trouble with varying degrees of success, but all require magnetic or electrical conducting materials. In the zero-gravity environment of space, containerless melting and processing are relatively simple and practical for all materials.

With no need for mechanical support of samples (either liquid or solid), thermal and electrical conduction to the sample from external sources and convective transfer and settling within the sample can be eliminated. This

(Text continued on page 193)

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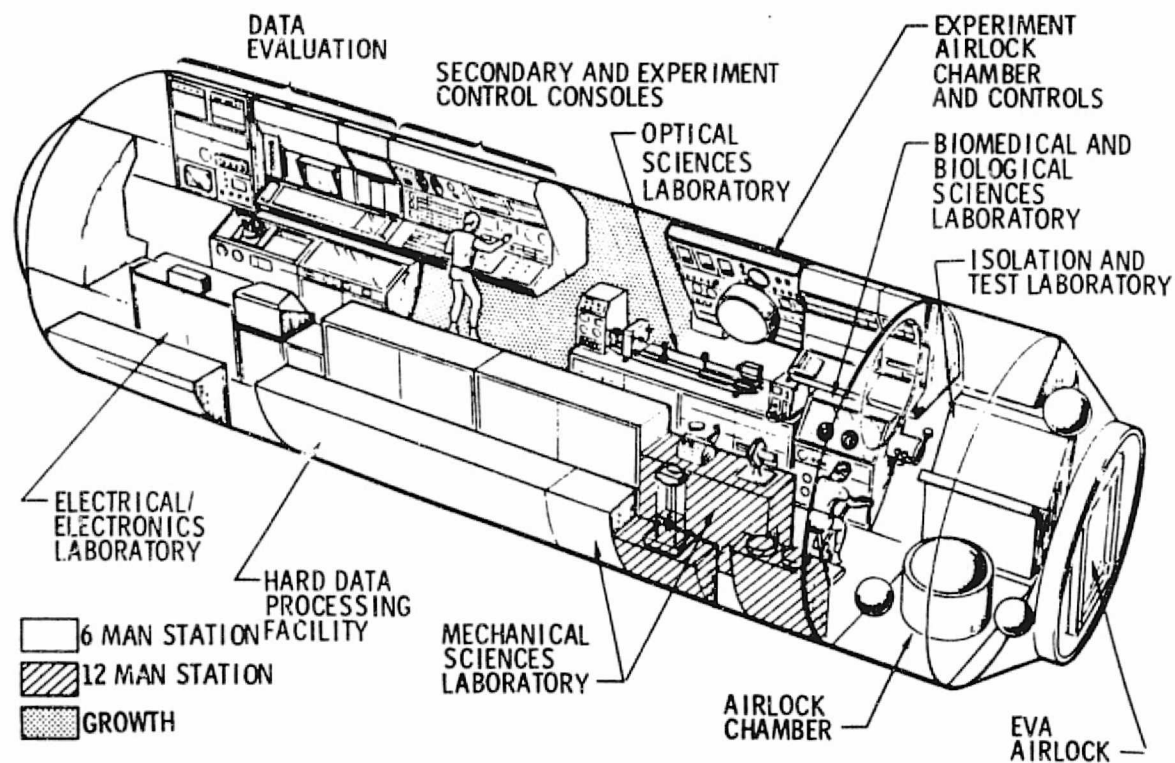
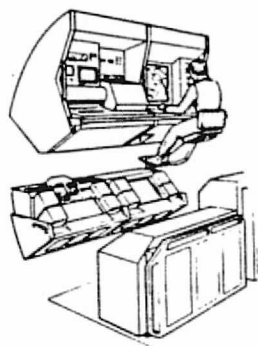


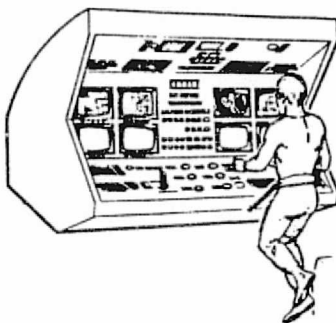
Figure 2.4-1. Representative General Purpose Laboratory

### DATA EVALUATION FACILITY



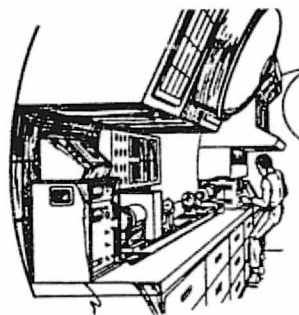
- ANALYZE, DIGITIZE AND CALIBRATE FILM
- ELECTRONIC IMAGE PROCESSING

### EXPERIMENT CONTROL CONSOLE



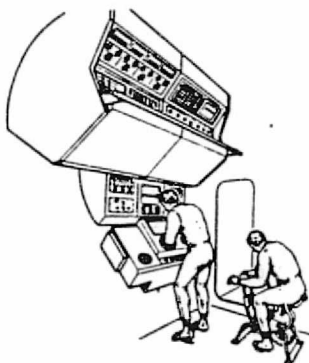
- MONITOR EXPERIMENTS
- EXPERIMENT ONBOARD CHECKOUT
- CAUTION AND WARNING
- SECONDARY COMMAND AND CONTROL STATION

### OPTICAL SCIENCES LABORATORY



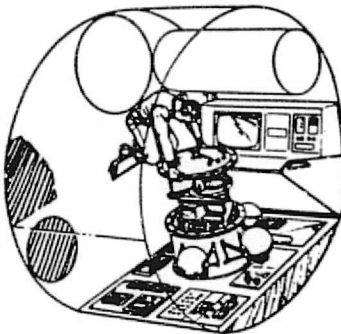
- CALIBRATE INSTRUMENTS
- OPTICAL ANALYSIS
- SCIENTIFIC AIRLOCK
- SUPPORT OPTICAL EXPERIMENTS

### BIOMEDICAL/BIOSCIENCE LABORATORY



- FLIGHT CREW WELL-BEING
- BIOSCIENCE RESEARCH
- SPECIMEN PREPARATION
- FLUID ANALYSIS

### EXPERIMENT AND TEST ISOLATION LABORATORY



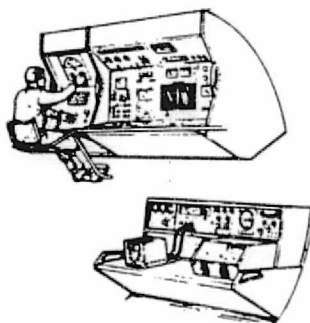
- ISOLATED EXPERIMENT OPERATIONS
- CHEMISTRY AND PHYSICS EXPERIMENTS
- SCIENTIFIC AIRLOCK
- REMOTE OPERATION

### MECHANICAL LABORATORY



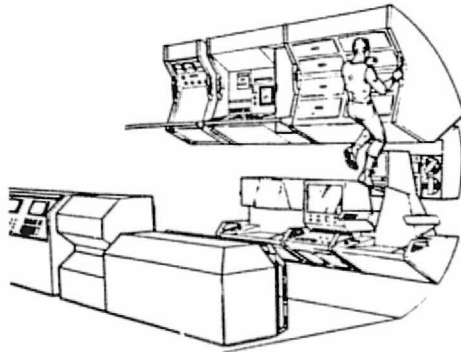
- MATERIAL TESTING AND ANALYSIS
- MECHANICAL WORK STATION
- GLOVE BOX

### ELECTRONIC/ELECTRICAL LABORATORY



- ELECTRONIC CALIBRATION
- CHECKOUT AND DIAGNOSTIC STIMULI
- MULTI-INSTRUMENT TEST STATION
- ELECTRONIC WORK BENCH

### HARD DATA PROCESSING FACILITY



- BLACK AND WHITE COLOR FILM PROCESSING
- EMULSION PLATE PROCESSING
- MICROFILM
- FILM VAULT

Figure 2.4-2.

Table 2.4-1. (Page 1 of 2)  
GPL MAJOR EQUIPMENT FOR MDSL

---

- Data Evaluation Facility
    - Multiformat viewer editor
    - Microfilm retrieval system
    - Automatic film reader
    - Copy machine
    - Stereo viewer
    - Image processing and data management control station
    - Working image storage
    - Permanent video storage
    - Permanent digital storage
    - Time reference unit
    - Printer
    - TV camera control unit
    - Video tape unit
    - Scientific computer
  - Optical Sciences Laboratory
    - Optical all-duty work station
    - Optical bench
    - Precision work fixture
    - Microdensitometer
    - Monochromator spectrometer
    - Modulation transfer function measurement system
    - Optical spectrum analyzer
    - Scientific airlock chamber
    - Precision optical window
  - Biomedical/Bioscience Laboratory
    - Biochemical and biophysical analysis unit
    - Bioscience glove box
    - Bicycle ergometer
    - Lower body negative-pressure device
    - Body mass measuring device
    - Biomedical display and control unit
-

Table 2.4-1. (Page 2 of 2)  
GPL MAJOR EQUIPMENT FOR MDSL

---

- Experiment and Test Isolation Laboratory
  - Hazard-detection system
  - Electrical and vacuum power center
  - Hydraulic/pneumatic all-duty work station
  - Cryogenic and fluid storage
  - High-pressure gas storage
  - Airlock/environmental chamber
  - Chemistry and physics glove box
  - Chemistry and physics analysis and storage unit
- Mechanical Laboratory
  - Mechanical work bench
  - X-ray diffraction unit
  - Experiment and isolation test lab monitor panel
  - Laminar flow glove box
  - Specimen structural tester
  - Metallographic tester and microscope
  - Thermostructural test equipment
  - X-ray generator
- Hard Data Processing Facility
  - Film and plate processors
  - Film storage
  - Video data display and control console
  - Microfilmer
  - Light table
  - Spectro photometer
  - Densitometer
  - Operations console
  - Display and control unit
- Electronic/Electrical Laboratory
  - Electronic all-duty work station
  - Multiinstrument test bench
  - Battery charger
  - High-voltage source
  - High-energy counter calibration equipment
  - Miniature glove box

permits better observation of internal electrical forces, brownian motion, and macroscopic motions due to other forces.

Much of the proposed materials science orbital research will be done by observation of optical patterns. Typical examples would concern the shape and stability of fluid interfaces, behavior of superfluids in zero gravity, and capillary flow in a weightless state. The final data taken will usually be photographed. However, the experimental apparatus may be run many times with "eyeball" observation of results (to determine program function) for each session of data photographed. Typically, such experiments would be run and rerun over a large range of variable parameters. Each "run" might represent a new setup that would be checked before recording data.

#### Earth Sciences

The MDSL effort in earth sciences will be primarily directed at the development of relatively small instruments for use in unmanned satellites. An important part of such work will be the parallel development of a data analysis and prediction system capability (as in weather phenomena). Thus, the research will not only involve test and evaluation of different sensors and optical systems (systematically varying numerous parameters to determine optimum combinations), but also actually producing data for use in the total system development. This will be "cut and try" testing with a subsequent need for laboratory flexibility and an ability to make rapid unplanned changes to test parameters or mechanical arrangements.

A key physical element in developing natural meteorological laws of cause and effect is cloud physics research. Cloud droplet formation, with the attendant release of heat, provides the energy that "runs" all important destructive storm phenomena. Experimental research into droplet formation processes has so far produced few usable results. Since the presence of gravity is believed to have prevented successful conclusion of this work, significant research effort will be devoted to operating "cloud chamber" apparatus on orbit.

## Solar Physics

It is well known that the atmosphere is opaque to many radiation bands important to astronomers, such as ultraviolet, x-ray, and low frequency and very high frequency RF. Thus, research in these areas can be meaningfully supplemented by space-based observations. This is particularly true of solar observations which probably benefit the most from association with a space platform. Because the important solar events are unpredictable transients, a continuous solar watch will be maintained. Continuous, nearly real-time analysis of high-resolution imagery (or even direct visual observations) will quickly identify the location and type of transient phenomena and appropriate instruments will be directed to the region of immediate interest. This pattern recognition and analysis will be performed by the laboratory specialists.

## Additional Research

A multitude of space research tasks have been proposed for MDSL in order to benefit from the environment of space (i. e. , reduced gravitational effects, enhanced earth viewing, and the absence of a blocking atmospheric layer in outward viewing). Abstracts of typical research activities in the fields of space biology, space astronomy, space physics, and earth observations which could be conducted as part of MDSL are listed in Table 2.4-2. The list includes the support and operational requirements placed on the GPL and/or SCB by each research activity. The material abstracted was developed for NASA by MDAC during the Earth Orbital Experiment Program and Requirements Study (Contract NAS1-9464).

### 2.4.4 Space Construction Base Requirements

The requirements imposed on the SCB by the MDSL research operations and the GPL are summarized in this section.

## Orbital Characteristics

- Orbital altitude: no overriding singular requirements, 185 km to 650 km (100 nmi to 350 nmi) preferred.
- Orbital inclination: no overriding singular requirement, 0 to 60 degrees preferred.

## Power

The GPL configuration shown in Figure 2.4-1 will require approximately 15 kW average power from the SCB.

(Text continued on page 202)



Table 2.4-2. (Page 1 of 7)

## LEGEND:

NR No Specific Requirement  
 N A Item Not Applicable  
 TBD To Be Determined after Additional Analysis  
 UNK Relationship Unknown

## SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
		(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B< (29) (degrees)	(12) Q (events/day)
1-BM-1	Cardiovascular	100	1,000	Film	Air	100 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-5	Medical Problems	240	1,200	NR	Air	1,200 + UNK	NR	NR	NR	NR	NR	N/A	N/A
1-BM-6	Stress Response	350(1)	870(1)	NR	Air	350 to 870 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-7	Nervous System	1	1	Film	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-8	Gastrointestinal	40	45	NR	Air	40 to 45 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-10	Blood and Urine	200	300	NR	Air	200 to 300 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-12	Instrumented Animals	100	100	NR	Air	100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-13	Pulmonary Function	50	55	NR	Air	50 to 55 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-14	Metabolism	20	27	NR	Air	20 to 27 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-15	Centrifuge Studies	280	5,300(2)	NR	Air	280 + metabolic	NR	NR	Ambient to 1.1(2)	NR	NR	N/A	N/A
1-BR-1	Sensory Behavior(4)	180	400	NR	Air	180 to 400 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-2	Group Dynamics	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-3	Complex Tasks	47	187	NR	Air	2,187 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-4	Skill Retention	200	5,300(2)	NR	Air	200 to 5,300 + metabolic	NR	NR	Ambient to 1.1(2)	NR	NR	N/A	N/A
1-BR-6	Performance Tests	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-1	Controls and Displays(3)	50	1,000	NR	Air	50 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	UNK	UNK
1-MM-2	Locomotion	40	50	NR	N/A	50	0.25	0.003	Ambient	NR	NR	N/A	N/A

NOTE: Numbers 1-BM-1, -2, -3, -9, -11 and 1-BR-5 were assigned to clusters that were later combined with others or eliminated.

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Table 2.4-2. (Page 2 of 7)

## SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical		Logistics (3) Special Handling	Environment		Stabilization		Acceleration (8) Level (g's)	Orbit Parameters		Viewing Restrictions	
		(1) Average (watts)	(2) Peak (watts)		(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)		(9) H (nmi)	(10) i (degrees)	(11) B < (29) (degrees)	(12) Q (events/day)
1-MM-3	Habitability	40	50	Film	Air	40 to 50 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-4	Activity Cycles	100	150	NR	Air	2,150	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-5	Performance Aids	345	425	NR	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-1	Phase Change	200	1,500	NR	Air	1,500	0.25	0.003	10 <sup>-4</sup> (5)	NR	NR	N/A	N/A
1-LS-2	Material Transport	800	1,500	NR	Air	1,500	0.25	0.003	10 <sup>-4</sup> (6)	NR	NR	N/A	N/A
1-LS-3	Atmosphere Supply	1,000	1,200	NR	Air	1,000	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-4	Water Management	100	250	NR	NR	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-5	Water Electrolysis	630	700	NR	Air	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-6	Food Management	3,000	6,000	NR	Air	700	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-7	Atmosphere Purification	300	400	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-8	Life Support Monitoring	TBD <sup>(8)</sup>	TBD <sup>(8)</sup>	NR	Air	TBD <sup>(8)</sup>	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-9	Waste Management	500	900	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-10	Heat Transport	1000	1,200	NR	NR	800	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-11	Crew Systems	TBD <sup>(8)</sup>	TBD <sup>(8)</sup>	NR	Air	TBD <sup>(8)</sup>	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-12	Maintenance and Repair	TBD <sup>(8)</sup>	TBD <sup>(8)</sup>	NR	Air	TBD <sup>(8)</sup>	NR	NR	Ambient	NR	NR	N/A	N/A
1-EE-1	Data Management	100	250	Film	NR	250	NR	NR	Ambient	NR	NR	UNK	UNK
1-EE-2	Structures	550	1,000	NR	NR	NR	0.25	0.003	Ambient	100 to 250	70	N/A	N/A
1-EE-3	Stability and Control	530	765	NR	NR	100	0.1	0.003	Ambient <sup>(7)</sup>	NR	NR	UNK	UNK
1-EE-4	Navigation and Guidance	100	TBD	NR	Cryo	100	0.25	0.003	NR	NR	NR	TBD	TBD
1-EE-5	Communications	50	50	NR	NR	50	0.25	0.003	NR	NR	NR	TBD	TBD
1-OE-1	Logistics and Resupply	400	400	NR	Air	400	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-2	Maintenance and Repair	200	200	Film	NR	200	0.25	0.003	Ambient	TBD <sup>(9)</sup>	TBD <sup>(9)</sup>	N/A	N/A
1-OE-3	Assembly and Deployment	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-4	Module Operations	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-5	Vehicle Support	NIL	NIL	NR	Air	NR	0.25	0.003	Ambient	NR	NR	UNK	UNK
2-VB-1	Preliminary Vertebrates	450	2,200	Film	Air and Steam	Metabolic	NR	NR	10 <sup>-5</sup> (10,11)	NR	NR	N/A	N/A
2-VB-2	Intermediate Vertebrates	450	2,200	Film	Air	Metabolic	NR	NR	10 <sup>-5</sup> (10,11)	NR	NR	N/A	N/A
2-VB-3	Advanced Vertebrates	450	2,220	Film	Air	Metabolic	NR	NR	10 <sup>-5</sup> (10,11)	NR	NR	N/A	N/A
2-IN-1	Preliminary Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10 <sup>-4</sup>	NR	NR	N/A	N/A
2-IN-2	Intermediate Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10 <sup>-4</sup>	NR	NR	N/A	N/A
2-IN-3	Advanced Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10 <sup>-4</sup>	NR	NR	N/A	N/A

Table 2.4-2. (Page 3 of 7)

## SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmil)	(10) i (degrees)	(11) B±(29) (degrees)	(12) Q (events/day)
2-P/T-1	Preliminary Protists	440	2,400	Film	Air	Metabolic	NR	NR	$10^{-4}$	NR	NR	N/A	N/A
2-P/T-2	Intermediate Protists	480	2,440	Film	Air	Metabolic	NR	NR	$10^{-4}$	NR	NR	N/A	N/A
2-P/T-3	Advanced Protists	540	2,550	Film	Air	Metabolic	NR	NR	$10^{-3}$	NR	NR	N/A	N/A
2-PL-1	Preliminary Plants	265	915	Film	Air	Metabolic	NR	NR	$10^{-5}(10,11)$	NR	NR	N/A	N/A
2-PL-2	Intermediate Plants	265	915	Film	Air	Metabolic	NR	NR	$10^{-5}(10,11)$	NR	NR	N/A	N/A
2-PL-3	Advanced Plants	265	915	Film	Air	Metabolic	NR	NR	$10^{-5}(10,11)$	NR	NR	N/A	N/A
3-OW	Optical Structure	930	960	Film	Cryo	TBD	$6 \times 10^{-6}$	$1.4 \times 10^{-6}$	NR(12)	Sync	NR	NR(14)	NR
3-XR	X-ray Sources	406	960	TBD	NR	773	$7 \times 10^{-5}$	$7 \times 10^{-6}$	NR(12)	100 to 400	NR	NR	NR
3-LF	Low-Frequency Radio	366	400	NR	NR	400	TBD(13)	TBD(13)	NR(12)	Sync	NR	NR	NR
3-OB	Optical Planetary	1,100	1,920	Film	Cryo	TBD	$7 \times 10^{-4}$	$7 \times 10^{-6}$	NR(12)	Sync	NR	NR(14)	NR
3-OS	Optical Surveys	170	960	Film	Cryo	TBD	$3 \times 10^{-4}$	$3 \times 10^{-6}$	NR(12)	100 to 400	NR	NR(14)	NR
3-SO	Solar Optical	TBD	TBD	Film	Cryo	TBD	$3 \times 10^{-4}$	$3 \times 10^{-6}$	NR(12)	Low	Sun Sync	None	None
3-OP	Stellar Photometry	170	960	TBD	NR	TBD	$3 \times 10^{-4}$	$3 \times 10^{-6}$	NR(12)	100 to 400	NR	NR(14)	NR(14)
4-P/C-1	Chemical Reactions	750	1,000	Film	TBD	TBD	0.25	0.003	$10^{-3}$	N/A	N/A	N/A	N/A
4-P/C-2	Liquid-Vapor Interface	400	500	Film	TBD	1,500	0.1	0.003	$10^{-5}, 10^{-6}(15)$	N/A	N/A	N/A	N/A
4-P/C-3	Heat Transfer in Zero-G	30	3,000	Film	Inert or Noble gas	3,300	0.1	0.003	$10^{-2}$ to $10^{-5}(17)$	N/A	N/A	N/A	N/A
4-P/C-4	Controlled Density	5,000	20,000	Film	Various(16)	TBD	0.1	0.003	$10^{-3}$ to $10^{-4}(17)$	N/A	N/A	N/A	N/A
4-P/C-5	E and M Fields	200	2,000	Film	TBD	2,000	0.1	0.003	$10^{-3}$	NR	NR	N/A	N/A
4-P/C-6	Super Materials	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	$10^{-2}$ to $10^{-5}(17)$	NR	NR	N/A	N/A
4-P/C-7	Levitation Melting	2,000	5,000	Film	TBD	TBD (5,000)	0.25	0.003	$10^{-3}$	NR	NR	N/A	N/A
4-P/C-8	Films and Foils	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	$10^{-3}$	NR	NR	N/A	N/A
4-P/C-9	Liquid Releases	175	200	Film	Air or He	Nominal	0.25	0.003	$10^{-3}$	NR	NR	N/A	N/A
4-P/C-10	Capillary Flow	250	400	Film	Inert + O <sub>2</sub>	400	0.25	0.003	$10^{-2}, 10^{-4}$ $10^{-6}(17)$	NR	NR	N/A	N/A
4-P/C-11	Superfluids	20	20	Film	NR	Nominal	0.25	0.003	$10^{-2}, 10^{-4}$ $10^{-6}(17)$	NR	NR	N/A	N/A
4-CR-1	Nuclear Component	10,000 (18,20,4)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-2	Primary e <sup>-</sup> and e <sup>+</sup>	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK

Table 2.4-2. (Page 4 of 7)

## SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical		Logistics (3) Special Handling	Environment		Stabilization		Acceleration (8) Level (g's)	Orbit Parameters		Viewing Restrictions	
		(1) Average (watts)	(2) Peak (watts)		(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)		(9) H (nmi)	(10) i (degrees)	(11) B<(29) (degrees)	(12) Q (events/day)
4-CR-3	Primary Gamma Rays	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-4	Heavy Isotopes	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-5	Antinuclei	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-6	Quarks	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-7	Unknown Particles	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-8	Albedo Particles	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-9	Differential p-p	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-10	Differential Spallation	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH <sub>2</sub>	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-1	SS Environment Interaction	TBD	TBD	TBD	TBD	TBD	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-2	Particle Dynamics	100	1,000	NR	NR	Nominal	0.25	0.003	NR	12,400	>55	UNK	UNK
4-PP-3	Thermal Plasma	TBD	TBD	NR	NR	Nominal	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-4	Auroral Processes	100	1,000	NR	NR	Nominal	0.25	0.003	NR	12,400	>55	UNK	UNK
5-N-1	Terrestrial Noise	25	25	NR	NR (21)	Nominal	1.0	0.05	NR	200 to 1,000	90	NR	TBD
5-N-2	Noise Identification	25	25	Film	NR (21)	Nominal	0.25	0.003	NR	TBD	55	NR	TBD
5-P-1	Ionosphere Propagation	25	25	NR	NR (21)	Nominal	0.25	0.003	NR	100 to 200	90	N/A	TBD
5-P-2	Troposphere Propagation	25	25	NR	NR (21)	Nominal	0.1	0.003	NR	Sync	0	N/A	N/A
5-P-3	Plasma Propagation	25	25	NR	NR (21)	Nominal	NR	NR	NR	100 to 200 (22)	40	N/A	N/A
5-P-4	Multipath Measurements	50	50	NR	NR (21)	Nominal	NR	NR	NR	100 to 1,000	NR	N/A	TBD
5-TF-1	Laboratory Deployment	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to Sync	NR	NR	TBD
5-TF-2	Demonstration and Test	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to Sync	NR	NR	TBD
5-CS-1	MM Wave Demonstration	350	400	NR	NR (21)	400	0.5	0.05	NR	NR	NR	NR	TBD
5-CS-2	Optical Demonstration	500	1,500	Film	NR (21)	1,500	0.5	0.05	NR	200 to 1,000	TBD	NR	TBD

Table 2.4-2. (Page 5 of 7)

## SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical		Logistics (3) Special Handling	Environment		Stabilization		Acceleration (8) Level (g's)	Orbit Parameters		Viewing Restrictions	
		(1) Average (watts)	(2) Peak (watts)		(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)		(9) H (nmi)	(10) i (degrees)	(11) B<(29) (degrees)	(14) Q (events/day)
5-NS-1	Navigation Techniques	50	100	NR	NR (21)	100	0.25	0.003	NR	100 to Sync (23)	55	NR	TBD
5-NS-2	Laser Ranging	500	1,500	Film	NR (21)	1,500	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-3	Autonomous Navigation	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	100 to Sync	NR	NR	TBD
5-NS-4	Surveillance Systems	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-5	Collision Avoidance	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-6	Search and Rescue	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
6-EP-1	Photographic Coverage	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-EP-2	Volcanic Activity	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/190
6-A/F-1	Crop Inventory	4,800	5,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	30 to 90	1/8 and 1/30
6-A/F-2	Soil Type Mapping	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1/8 and 1/30
6-A/F-3	Crop Identification	4,600	5,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1/8
6-A/F-4	Crop Vigor and Yield	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	60 to 90	1 or 1/8
6-A/F-5	Wildfire Detection	2,200	3,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	30 to 90	1 and 2
6-G/C-1	Multisensor Mapping	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-G-1	Rocks and Soils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1/10
6-G-2	Use of Earth's Crust	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/10
6-G-3	Geologic Disasters	3,300	3,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	25 to 90	1 and 1/30
6-G-4	Geothermal Sources	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/100
6-G-5	Minerals and Oils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	15, 30, 60	1/100
6-G-6	Land Forms	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1/10
6-H-1	Water Pollution	1,300	2,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1
6-H-2	Flood Warning	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	125 to 275	55	30 to 90	1 and 1/8
6-H-3	Synoptic Lake Inventory	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1/90
6-H-4	Synoptic Ice Inventory	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	55	30 to 90	1/90
6-H-5	Soil Moisture	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	90	30 to 90	1/8
6-H-6	Underground Sources	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	50	0 and >30	1/180
6-H-7	Major River Basins	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 175	55 to 68	<30 and 0 to 90	1/90
6-M-1	Boundary Layer Exchange	600	900	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 300	30 to 70	NR	NR
6-M-2	UHF Sferics Detection	500	800	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 400	30 to 55	NR	NR
6-M-3	Atmospheric Density	65	100	Film (24)	NR	Nominal	0.02 (27)	0.05	NR	100 to 300	0 to 50	NR	NR

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Table 2.4-2. (Page 6 of 7)  
SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
		(1) Average (watts)	(8) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B-tilt (29) (degrees)	(12) Q (events/day)
6-M-4	Zero-G Cloud Physics	200	200	Film (24)	N <sub>2</sub> , O <sub>2</sub> , CO <sub>2</sub> , H <sub>2</sub> O	Nominal	NR	NR	10 <sup>-5</sup>	N/A	N/A	N/A	N/A
6-M-5	Atmospheric Pollutants	500	800	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	200 to 300	30 to 55	30 to 90	NR
6-M-6	Special Area Studies	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	100 to 300	20 to 30	TBD	TBD
6-O-1	Ocean Pollution	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-2	Solar Energy Partition	800	1,100	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-3	Ocean Population Dynamics	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-4	Currents and Tides	3,100	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-5	Ocean Physical Properties	3,000	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 200	55	NR	1
6-O-6	Ocean Solid Boundary	1,500	2,200	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-7	Ocean Surface Activity	700	900	Film (24)	Cryo	TBD (25)	0.5	0.03 (28)	NR	100 to 250	55	NR	1

#### REMARKS:

- (1) Power levels required for thermal enclosure; when not used power levels reduced to 40 to 45 watts.
- (2) Onboard manned centrifuge required. High starting and run up power requirements may require secondary batteries. Stabilization and control disturbances need to be noted.
- (3) Research may be accommodated by coordination of design of onboard stabilization and control subsystem.
- (4) Recommends Space Station rotation and/or centrifuge.
- (5) Investigations require this acceleration level for periods of 1 hour.
- (6) Investigations require this acceleration level for periods of 5 hours.
- (7) Some of the functions performed by onboard investigators and members of the crew produce significant disturbances. The effect of these disturbances on the spacecraft could be measured to obtain important data concerning disturbance torques and accelerations.
- (8) Research data may be derived from other experiments; unique requirements need to be determined when experiment groupings are resolved.
- (9) Orbit must be selected so as to be safe for EVA.
- (10) Some investigators may settle for 10<sup>-4</sup>g.

SPACE RESEARCH FACILITY INTERFACE SUMMARY

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- (11) Some experiments require onboard centrifuge.
  - (12) The optical instruments need to be isolated from vibration and torque disturbances produced in the spacecraft.
  - (13) Scanning required at a 6-degree/second rate.
  - (14) Protection required to prevent instruments from inadvertently pointing toward the sun.
  - (15) Level required for periods of 2 hours.
  - (16) Gases required include  $N_2$ ,  $O_2$ , He, A, and others.
  - (17) May require onboard centrifuge or Space Station rotation.
  - (18) Power levels required for cooling superconducting magnet by closed system. For passive resupply of cryogen total power would be about 3,000 watts.
  - (19) Periodic major reconfiguration of experimental apparatus may be required at 1- to 3-month intervals.
  - (20) Depending on duty cycle, high-power level demands may require secondary batteries.
  - (21) No specific atmosphere requirements except for no corrosive components.
  - (22) Orientation of sensors is critical during reentry in order to make measurements of spacecraft perturbations or plasma.
  - (23) Surface and airborne targets required to 100,000-foot altitude.
  - (24) Retrieval and resupply of photographic material considerations may result in onboard processing requirements.
  - (25) Amount of cooling for infrared detectors depends on details of open or closed loop refrigeration installation.
  - (26) Spacecraft roll maneuvers required to calibrate microwave radiometer.
  - (27) For target acquisition 1 arc-min, for target tracking 2 arc-sec.
  - (28) Spacecraft yaw maneuvers required to calibrate radar altimeter/scatterometer.
  - (29) Angle between spacecraft-sun line and orbit plane.
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### Personnel

The GPL will employ a crew of six scientists and technicians. The crew will rotate at 90 and 180-day intervals.

### Data Management/Communications

Requirements on the SCB in addition to a normal voice link to ground will be a digital data link capable of transmitting up to 10 Gb of data to the ground each day.

### Workshop

The MDSL research will require the use of a pressurized general-purpose workshop capable of repairing and calibrating electronic and mechanical research equipment. A volume of approximately  $20 \text{ m}^3$  will be required.

### Environmental Control

Temperature, humidity, and cleanliness requirements for the GPL are those for SCB shirtsleeve activity.

### Waste Management

Waste management will be accommodated by mission hardware.

### Contamination

Effluents, outgassing, and propulsion products must not impinge on or form clouds ( $\text{TBD particles/cm}^3$ ) about the GPL to avoid degradation of earth and space science sensors or optical windows.

### Acceleration and Noise Control

During certain micro-gravity research, acceleration must be maintained at less than  $10^{-3} \text{ g}$ . The acoustic level must be less than 40 db at all times.

### Logistics

Resupply will be accomplished as an adjunct to Shuttle flights whose primary purpose is the transport of various mission hardware.



## 2.5 LIVING AND WORKING IN SPACE

A review of the objectives projected in this study indicates that significant direct participation by man in Space Construction Base (SCB) development will be necessary. With potentially large on-orbit crew requirements, improvement in man's ability to live and work in space will be extremely beneficial. Man's ability to tolerate the space environment for long periods of time is by no means apparent from the data accumulated so far. Therefore, a systematic investigative approach is needed to obtain additional data that will provide a firm basis for defining man's role in SCB operations.

The primary goals associated with a living and working in space (LWIS) program are to:

- A. Better understand physiological problems which degrade human performance and/or physical health and processes, and develop methods of controlling or counteracting them.
- B. Establish the capability for manned space flights as lengthy as 720 days.
- C. Optimize man's on-orbit productivity by determining his capabilities to work in the space environment, then providing the environment, tools, work cycles, etc., that allow maximum use of man's capabilities.

### 2.5.1 Mission Overview

Selected research in life sciences is necessary to provide data for use in demonstrating the value of long-term LWIS projects compared with other man-in-space objectives. The early period of LWIS experimentation (1984-1987) will verify and extend the biological systems research already conducted on Skylab and Apollo flights. The experiments to be performed would include investigations to develop predictive and control techniques for inhibiting motion sickness, vestibular problems, cardiovascular degradation, etc. Extended on-orbit experimentation (45 to 90 days or more) would be required in order to properly assess the value of the developing techniques.

The specific mission objectives will evolve with time and, in the growth version (1987 +), be increasingly oriented toward determining man's

productivity during fabrication and assembly operations. However, for study purposes the total scope of this objective is restricted to selected research activities. Zero gravity ( $<10^{-3}$  g's) is required for experimentation but orbital altitudes and inclination are not constraining. Research related to LWIS that is directed toward a specific problem in space (e.g., large antenna assembly) is considered part of that specific space objective for purposes of this study.

#### 2.5.2 Mission Hardware Description

The hardware required for early experimentation (1984-87) and the growth version (1987 +) consists of equipment related to the performance of the experiments identified in the preceding section. Emergency medical care equipment is included.

Much of the equipment to be used during the early missions is expected to be selected from equipment developed, qualified, and flown on Spacelab. It is premature to define a specific list of equipment for the SCB research program until the experiments are selected. However, representative major equipment items that could be included in the initial and growth versions of the SCB are listed in Table 2.5-1. This equipment can be mounted in racks in a crew-related module or in a general purpose laboratory. The racks must be designed to permit selected equipment to be changed to accommodate various experiments.

Preliminary concepts for each of the experiment phases are shown in Figures 2.5-1 and 2.5-2.

The initial station should permit the accommodation of LWIS equipment equivalent to 1 or 2 m in station length (one-side only). The growth station should accommodate approximately 2-1/2 times as much equipment. All of this equipment requires the normal shirtsleeve atmosphere.

The mission hardware for the initial phase will either have been flown on Shuttle/Spacelab, and therefore be considered fully qualified for SCB, or will consist of new designs fully capable of meeting the SCB/Shuttle design

Table 2.5-1  
TYPICAL LUIS EQUIPMENT REQUIREMENT

Typical Equipment Item	Initial Phase (1984-1987)	Growth Phase (1987 +)
Cameras/film	X	X
Recorders (voice)	X	X
Signal conditioning rack/couplers	X	X
Crew mobility aids/restraints	X	X
Gas supplies/manifold	X	X
Waste storage device	X	X
Power supply and conditioning equipment	X	X
Refrigerator	X	X
Freezer	X	X
Mass spectrometer	X	X
Gas analyzer	X	X
Biomedical multichannel recorder	X	X
Support kit(s)	X	X
Exercise equipment	X	X
Blood processing centrifuge	X	X
Oscilloscope	X	X
Small vertebrate holding facility and support		X
Surgical/experiments bench		X
Microscope and supporting kits		X
Video monitor	X	X
Body mass measuring device		X
EVA monitoring equipment*		X
Fabrication monitoring devices*		X
Assembly test monitoring devices*		X
Miscellaneous experiment-peculier equipment	X	X
	Mass $\approx 300$ kg	750 kg
	Volume $\approx 1.3$ m <sup>3</sup>	3.3 m <sup>3</sup>
*For measuring and assessing man's productivity.	Power (W)	
	Average 500	1000
	Peak 1000	2000

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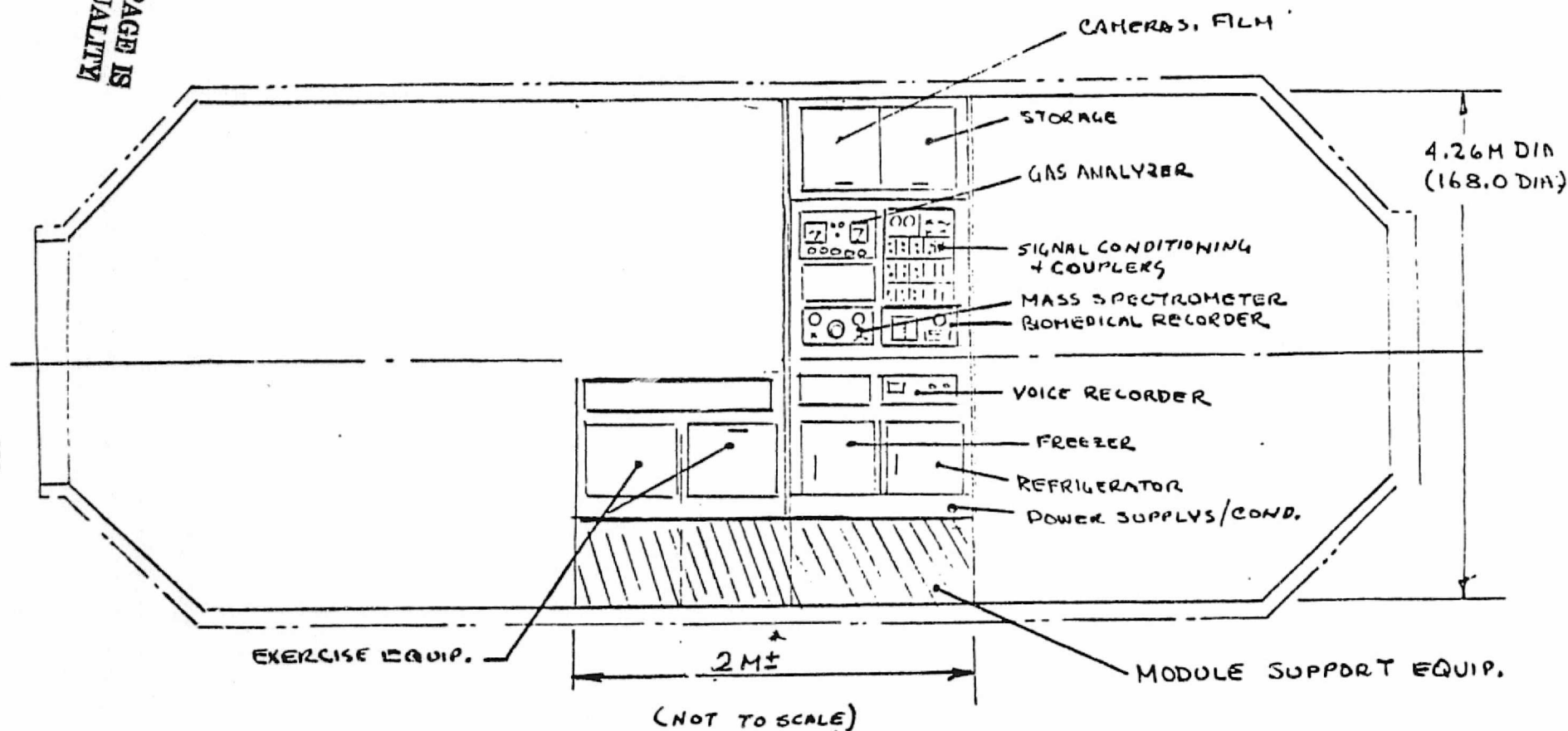


Figure 2.5-1. Living and Working in Space Mission Hardware, Initial Phase (1984-1987)

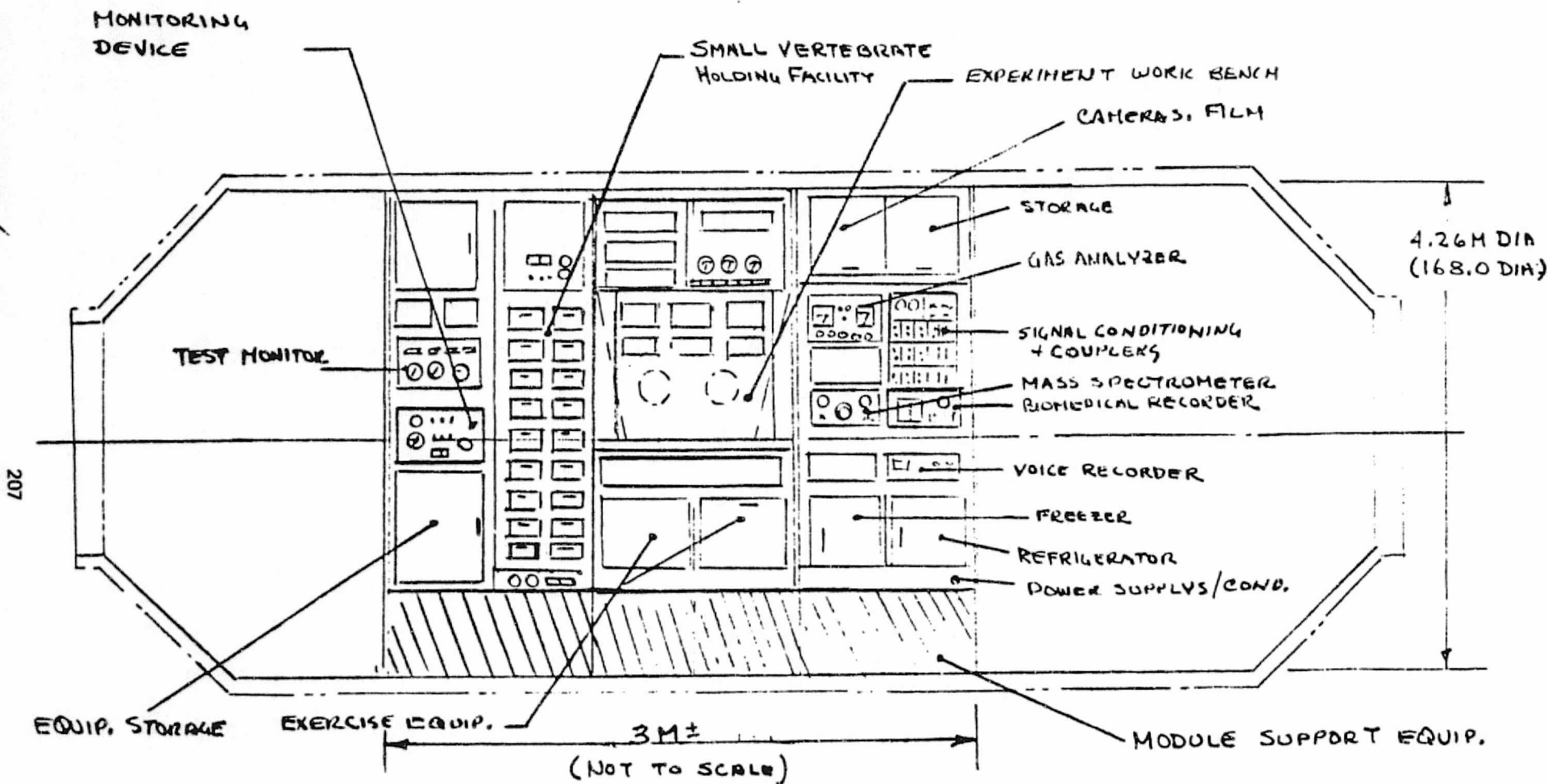


Figure 2.5-2. Living and Working in Space Mission Hardware, Growth Phase (1987+)

requirements. The design life of all equipment will be a minimum of TBD, and up to TBD for equipment planned for continuous experimental use (recorders, etc.).

### 2.5.3 Activity and Test Descriptions

The activities and testing during the initial phase of the SCB project must obtain data from the onboard crew to better understand physiological problems which degrade human performance and/or health, and to develop methods of controlling or counteracting these problems. The feasibility of such testing has been demonstrated by Skylab. Continued testing of this nature is also planned for Spacelab. The SCB testing should be included in program options at the time of earliest base manning. Basic research in the life sciences is not considered a part of this research, but could be a part of other space or multidiscipline laboratory programs. The detailed protocol of these experiments is beyond the scope of the current study, but the test equipment under consideration is believed to be typical of that which will be required.

As the activities move into the growth phase, tests will be directed toward longer-duration studies and monitoring and optimizing man's on-orbit productivity.

The time needed for the crew to perform the specific experiments (TBD) can be approximated based upon earlier analysis. Two examples of human vestibular studies that might be performed include the effectiveness of motion sickness drugs in weightlessness and mechanisms involved in vestibular adaptation to zero-g. The initial phase will require the dedication of the major portion of one crewman's time to the LWIS project, and the use of all other crewman as subjects for obtaining data. The growth phase will require the use of two crewmen full time. The daily dedicated crew time allocation is assumed to be:

<33%	Experiment research and operations
33%	Sleep
>33%	Meals, personal hygiene, rest and recreation, and unscheduled time.

One to 2% of all crew members' time should be available for use in obtaining LWIS data. Additional monitoring and observing will be done on a noninterference basis.

LWIS crewmen testing would occur on a daily basis as indicated in Figure 2.5-3. Certain experiments would be continued for the longest periods possible. A 90-day minimum is desired. Later tests (growth phase) with small vertebrates could last one year or longer on orbit. Examples of animal studies to be performed include (1) small-mammal experiments to measure the absolute relationship between the length of exposure to zero-g and fluid volume shifts; (2) bone marrow changes in zero-g; and (3) determination of bone demineralization in weightlessness for long-duration exposures.

#### 2.5.4 Space Construction Base Requirements

No unusual LWIS requirements are foreseen for the SCB. LWIS requirements for both the initial and growth versions involve the station in the areas of (1) accommodations; (2) avionics, data management, and electrical power; (3) environmental control and thermal control, and (4) crew. The requirements are summarized in Table 2.5-2 and discussed below.

##### 2.5.4.1 Power

Typical electrical power profiles required by the initial and growth LWIS experiments are shown in Figure 2.5-4. The SCB will be required to furnish power as shown in Table 2.5-2 (e. g. , 28V or 400 Hz ac) to accommodate the various equipment item requirements anticipated for on-orbit operation. Certain equipment such as freezers and refrigerators must be operated constantly, but this operation is cyclic in nature and depends upon use and design. Specimen-holding facilities that provide a controlled atmosphere (for rats for example) will require continuous power, e. g. , to operate fans to control excrement odors and circulate air for temperature control. Most other items are used only during the actual experiment period. Some data-monitoring capability will be required all the time.

##### 2.5.4.2 Control Data System

Much of the biomedical-peculiar data recording, processing, and storage will be accomplished using the type of LWIS equipment noted in Table 2.5-1

\* REPEATS DAILY FOR 1 or 2 CREWMAN  
DEDICATED TO LAWS

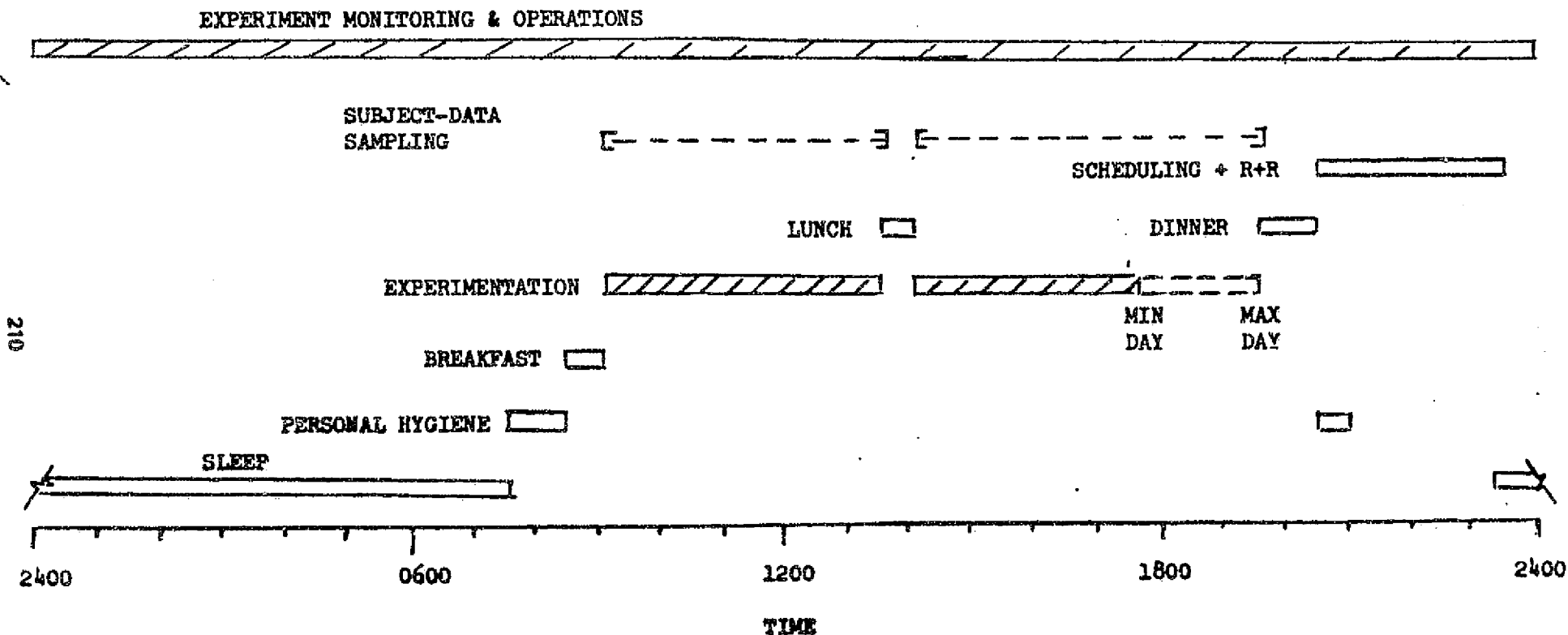


Figure 2.5-3. Typical Timeline\* (One Day) for LWIS Experimentation



Table 2.5-2  
LWIS REQUIREMENTS FOR THE SPACE CONSTRUCTION BASE

	Initial LWIS	Growth LWIS
	One to Two 1-m Racks of Equipment	Two to Three 1-m Racks of Equipment
<b>Accommodations</b>		
Volume (m <sup>3</sup> )	1.3	3.3
Mass (kg)	300	750
<b>Avionics/Electrical</b>		
Command data management system, rate storage (min)	45 kbps	75 kbps
Film (kg/90 days)	30	30
Power, avg/peak (W)	500/1000	1000/2000
28 V dc		
60 Hz ac		
400 Hz ac		
<b>Environmental/Thermal Control</b>		
Avionics cooling	X	X
Atmospheric cooling	X	X
Shirtsleeve (crew)	X	X
<b>Miscellaneous</b>		
Waste mgmt (kg/90 days)	5	10
Crew	1	2

Note: The facility must provide appropriate up/down data and voice links in order to utilize the expertise needed to make decisions in areas outside the ability of the onboard crew.

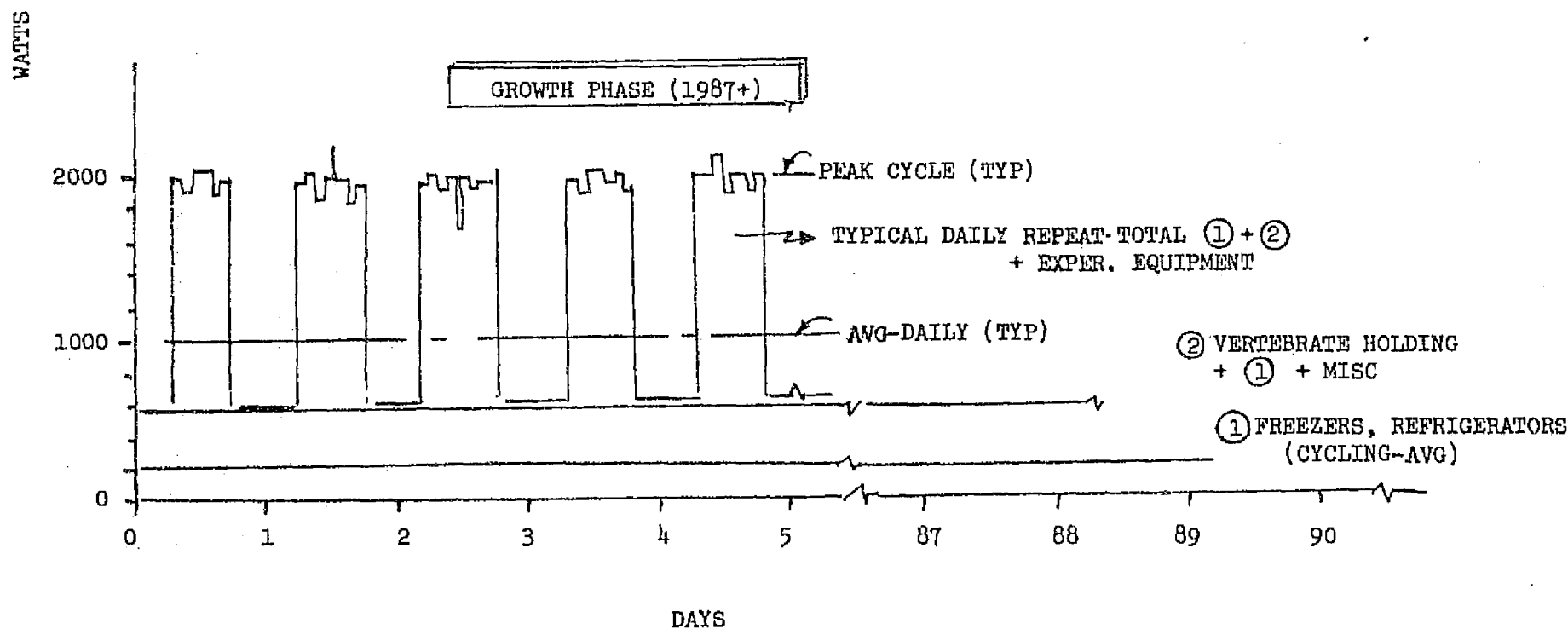
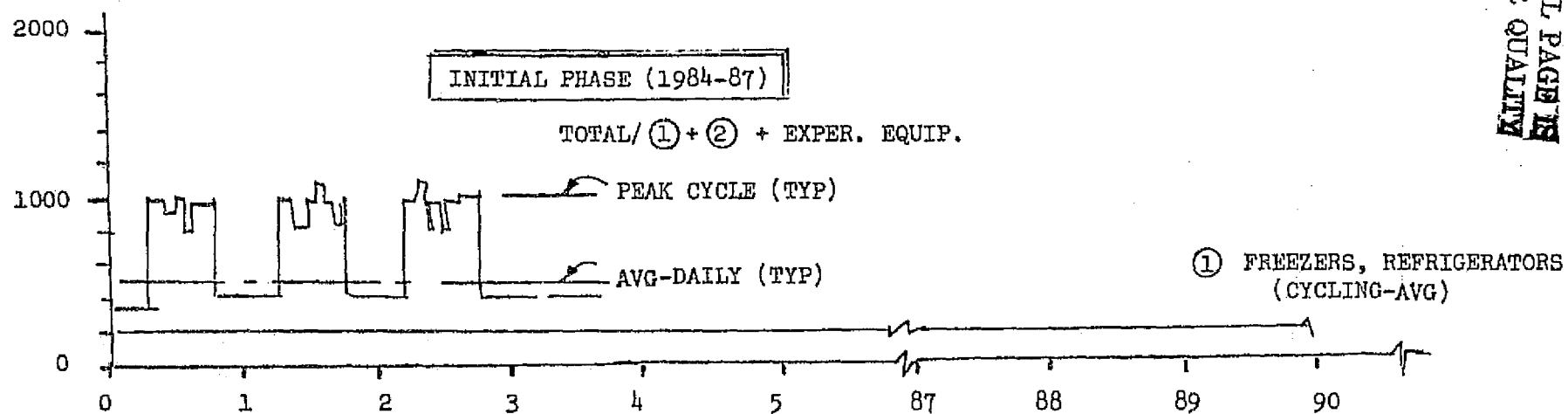


Figure 2.5-4. Typical Electrical Power Profiles for LWIS

and Figures 2.5-1 and 2. However, the basic SCB facility must provide the means to transfer data to other SCB control modules, and to the ground and return. Data interfaces consist of those for the acquisition of digital, analog, video, and voice signals in a variety of forms. The data rates based upon past analyses are minimal, as indicated in Table 2.5-2.

#### 2.5.4.3 Environmental and Thermal Control

The test equipment to be defined must be compatible with the SCB environment. It is assumed that the necessary EC/TC support is provided by the basic SCB modules. Both atmospheric and avionics (air or cold plate) cooling are considered necessary. Heat loads generated by the LWIS equipment are approximately equal to the electrical power being consumed -- that is 500 to 2000 W as shown in Figure 2.5-4 -- plus crew metabolic heat. In the growth case, the metabolic heat of the small vertebrates (e. g. , 36 rats) are included.

#### 2.5.4.4 Waste Management

It is assumed that an SCB system will store, control, and transfer crew waste needed for medical evaluation. Specimen and other LWIS wastes will be accommodated using LWIS mission hardware. The quantity and type are TBD.

#### 2.5.4.5 Personnel

The LWIS experiments will require that the crew be monitored to obtain data. The initial SCB crew should have at least one crewman specialist in biomedicine and manned systems. The larger growth version should have two. Additional crewmen must be cross-trained for support as needed.

#### 2.5.4.6 Safety

Potential hazards may exist that are associated with the use of radioactive isotopes as biological tracers in such studies as fluid and electrolyte balance and bone demineralization.

#### 2.5.4.7 Logistics

The basic equipment required to support the first year of operation should be included in the initial launch of a module (portion of crew module or other).

Resupply requirements will include new or replacement equipment (10% of initial launch weight per 90 days), consumables (TBD, estimated to be 0.5 to 1 kg per 90 days), and waste products (TBD, estimated to be 5 to 10 kg per 90 days). The resupply and return of five specimens in the growth phase must be considered.

## 2.6 SENSOR DEVELOPMENT

### 2.6.1 Mission Overview

Sensor development involves the orbital research, development, and testing of optical sensors and sensor systems in the IR, VIS, and UV spectra for a broad range of earth surveillance missions. Data gathered from these sensors could be used for assessing the production and management of food and forestry resources, predicting and protecting the environment, exploring energy and mineral resources, and for general research in the earth sciences. In addition, astronomical observations could be made with such sensors.

These development efforts would utilize the low-gravity and vacuum environments of space to develop high-performance sensor components such as glasses with uniform chemical and optical properties, distortion-free lenses, and large detector crystals. Sensor systems would then be tested on actual rather than simulated subjects, and developed in the conditions of intended usage.

The space development and testing would be done at an orbital altitude of 320 to 435 km (200 to 270 nmi) and inclination of 28.5 deg. Typical applications of the optical sensor systems include remote sensing and earth resource satellites, atmospheric sounding satellites, astronomical telescopes, and optical communications links.

### 2.6.2 Process and Mission Hardware Descriptions

#### Processes

Three levels of sensor development activity can be anticipated during the 1984-1996 time period. The first level would be applied research in a general-purpose R&D space laboratory. The second would involve the design and development of processes and major components for sensor systems and the initial construction and test of complete sensor systems. The third level, to be reached circa 1996, would concentrate on the construction, test, and operation of more complex and sophisticated systems. Because of its greater near-term predictability and more significant impact on the SCB, the second level of development will be emphasized here.

The processes that might be accomplished during the second level of development include:

- Final finishing and assembly of optical and other components.
- Application of surface coatings including evaporation.
- System or subsystem calibration and alignment of optical systems.
- Acceptance testing of delivered components.
- General-purpose light machining, forming, and electron beam and laser welding.

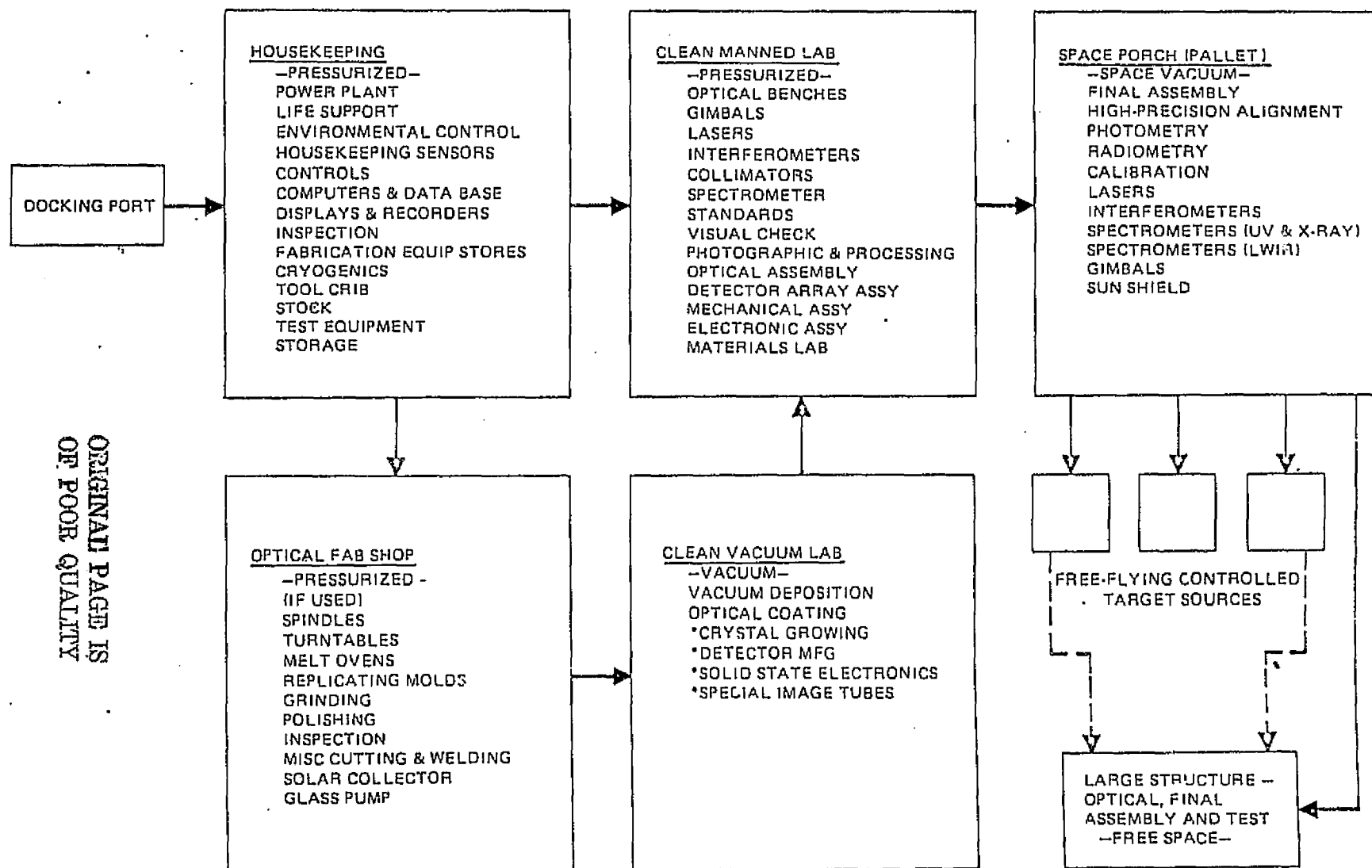
#### Mission Hardware

The mission hardware functions necessary for sensor development are indicated in Figure 2.6-1.

The first-level sensor development would require an optical work station, an airlock, optically flat windows, and basic instrumentation including such items as microdensitometers, spectrometers, and optical spectrum analyzers. This work might be done in a general purpose laboratory.

Second-level sensor development would require a dedicated module, 4.5 by 15 m, divided into the functional segments shown in Figure 2.6-1. The module would require the following capabilities for test and evaluation of optical components and sensors.

- A scientific airlock for exposing instruments to the space environment.
- An optically flat, broad spectrum transmission window in the airlock.
- Stable platforms (gimballed) for instrument mounting (0.1 to 3.0 arc-sec accuracy).
- Six small (0.3 m) remotely controlled target subsatellites operating at distances of 1 km or more.
- Docking for the small subsatellites.
- Calibration equipment, a digital computer, polishing tables, microscopes, collimators, spectrophotometers, lasers, and calibrated light and IR sources.
- Dynamic isolation systems.
- Pallet for external monitoring of sensors.



\*PROBABLY TO BE DONE BY OTHER OBJECTIVE ELEMENTS

Figure 2.6-1. Optical Sensor Development Functional Diagram

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Third-level sensor development would require a more sophisticated facility in a free-flying module operating in conjunction with the earlier module which can remain attached to the SCB. As in the earlier module, numerous remotely controlled small subsatellites would be required. The basic equipment complement would be the same as for the second-level module. The equipment would include interferometers, solid-state detector matrices, magnetic tape recorders, spectrographs (normal, Echelle, Slitless), plate cameras (5-inch, 9-inch, and larger), cine frame cameras—35 mm, image intensification systems, secondary electron conduction vidicons, image orthicons, and filter assemblies.

The free-flying module would be designed for a minimum of 30 days of self-sustaining operation, potentially in a sun-synchronous polar orbit. Average power requirements are estimated to be 100 kW. Module operation and sensor development would require a crew of 8, including 3 optics technicians for mirror molding and polishing, 1 optical engineer, 2 sensor engineers, and 2 assemblers.

The profile of a representative second-level development module is shown in Figure 2.6-2. The key resources required for the module include an optical fabrication shop; a clean, pressurized, manned laboratory; a clean vacuum laboratory; and a pallet for final assembly or mounting of sensors and instrumentation.

The optical shop will include facilities for grinding, polishing, inspection, cutting, and welding. The manned laboratory will include optical benches, gimbaled platforms, and appropriate instrumentation, including optical test, calibration, and alignment equipment. The vacuum laboratory will include facilities for vacuum deposition, preparation of optical coatings, and detector assembly.

It has been suggested that melting glass and forming glass lenses and mirrors with greatly improved optical characteristics is possible in the zero-g environment. If this proves feasible, and if the electrical energy supply is limited, melting of glass might require the installation of a large solar collector and the construction of a solar furnace as shown in Figure 2.6-2.



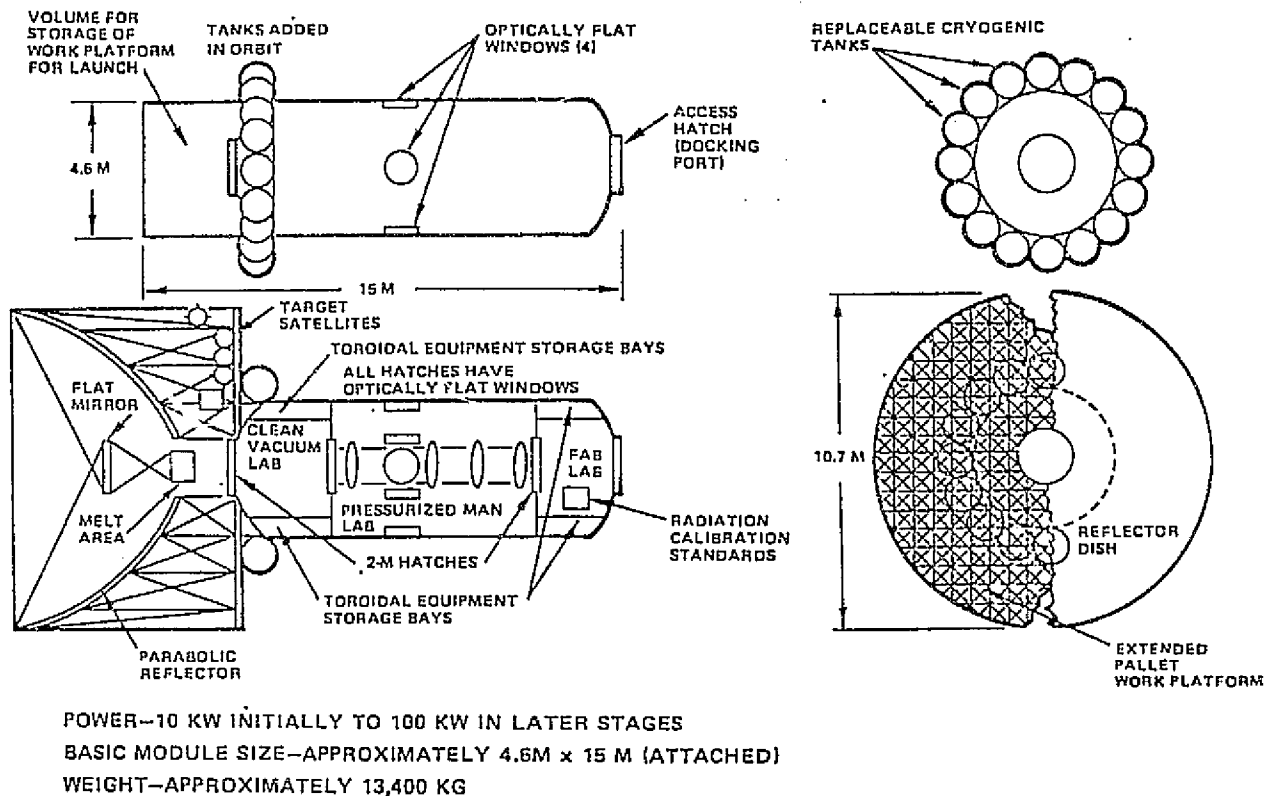


Figure 2.6-2. Representative Optical Sensor Development Module

### 2.6.3 Activity Description

The module will support orbital fabrication and development testing of normal-incidence optical sensors and sensor systems, along with the instrumentation to be used in the systems. Infrared, visible, and ultraviolet spectral regions are the specific areas of interest.

Because of the clean environment and absence of buoyancy in space, it may be possible to produce uniform, high-quality glass blanks with predictable optical characteristics. Such a process will require a shrouded, controlled environment to control outgassing and cooling rates or radiation damage to some of the additives which create the desired optical characteristics. Glass is a super-cooled liquid without sharp phase transitions from liquid to solid state. As glass cools, its viscosity increases to a point where it appears to be a solid.

The critical points in this cooling cycle are (1) the softening point which is the lowest temperature (or the highest viscosity) at which glass deforms

under its own weight, and (2) the annealing point or the highest temperature to which a finished glass product may be raised (without incurring deformation due to its own weight) to remove locked-in stresses produced during fabrication, grinding, and polishing processes.

These considerations suggest several possibilities for space applications in the manufacturing of optics. It may be possible to "cast" finished optical elements in space without deformation and thermal stress problems that are incurred when such processes are performed on earth.

Functions which might be performed in space include the following:

1. Assembly of and servicing sensors for reconnaissance satellites, remote sensing and Earth resource satellites, Earth mapping satellites, atmospheric sounding satellites, ocean and area surveillance satellites, arms control satellites, and astronomical telescopes and sensors.
2. Manufacture of sensor or telescope mirrors, crystal growth, filter coatings, deposition photo-tubes, detectors, and arrays where high vacuum is needed.
3. Testing of long-wavelength infrared sensors where cryogenic backgrounds and remote sources are available for calibration and testing.

During the first level, noncircular aspheric optical mirrors will be produced, with diffraction gratings up to 3400 lines/mm on their surfaces. High-reflective coatings will be made for the XUV wavelength region. Cryogenic cooling to 1.5°K and the optics of diffraction-limited quality for 1-m and 3-m telescopes will be investigated.

Before beginning second-level work in the dedicated module, the crew will remove protective covers and launch supports, erect secondary mirror supports, prepare work areas, and align and calibrate the tools, instruments, and support equipment.

They will then develop in-space optical instrument alignment and mirror figure techniques, improved materials for primary mirrors leading to

diffraction-limited quality optics, and film handling and storing techniques. They will utilize previously developed filters for IR spectroscopy, high-resolution recording media of the electronic or photographic-emulsion type, and electronic imaging techniques effective in the IR region from about 1 to 1,000 $\mu$  wavelength.

The crew will maintain, repair, and replace accessible components such as actuators and sensor packages for which spare parts can be provided. They will also replace existing sensors and other auxiliary equipment with more advanced units as they are developed and periodically remove exposed film and restock it as necessary.

A typical 1-m IR normal-incidence telescope has been estimated to require scheduled maintenance 6 times a year, involving 8 man-hours and 31.75 kg of test equipment.

#### 2.6.4 Space Construction Base Requirements

The following support functions will be required from the Space Construction Base for the second-level module.

##### Special Devices

A two-armed crane will be required that can reach 25 m. Seven degrees of freedom will be required to permit motion of the crane body (yaw), shoulder joint (pitch and yaw), elbow (pitch), and wrist (pitch, yaw, and roll).

##### Power

Average power required will be 10 kW for 8 hours, with a peak power load of 27 kW for 0.1 hour.

##### Data and Communications

A serial data rate of up to 1 Mbps is required for transmission of data to the ground and for collection of sensor data.

##### Orientation

The required pointing accuracy is up to 1.0 arc-sec for 12 hours, while oriented at stellar, solar, or terrestrial objects.

### Stabilization

Stabilization of 1.0 arc-sec is required for 12 hours, with a stability rate up to 0.1 arc-sec/sec.

### Personnel

Accommodations are required for two to four crewmen.

### Acceleration and Noise Control

The acceleration during activities requiring a micro-gravity environment (e.g., glass melting and lens casting) must be limited to  $10^{-3}$  g. The maximum noise permitted will be 70 db.

### Environmental Control

The temperature must be maintained at 20°C and the humidity at 10% under 100,000 class clean room conditions.

### Contamination

Effluents, outgassing, and propulsion products must not impinge on or form clouds (TBD particles/cm<sup>3</sup>) about the sensor development area to avoid contamination of sensors and optical windows.

### Logistics

Approximately 55 kg/day of consumables (N<sub>2</sub>, O<sub>2</sub>, and He) will be required.

Four Shuttle flights a year will be required for crew rotation and resupply. The second- and third-level sensor development modules would employ OTV's to transport the optical systems constructed in orbit to their operational stations. For second-level development, the OTV would deliver payloads of 1000 to 9000 kg to polar and geosynchronous orbits, and for third-level development, it would deliver 13,400 kg to polar orbit.

### 3. PROGRAM OPTIONS

In Part 1 of the SSSAS, three types of programs were identified that appeared to warrant further study:

1. Programs based on low earth orbit (LEO) operations only, designated "L options."
2. Programs based on operations in both low earth orbit and geosynchronous orbit (GEO), designated "LG options."
3. Programs based on operations at geosynchronous orbit only, designated "G options."

Each of these was divided into two options, as follows:

1. L options
  - A. L' - Uses a shuttle-tended mode of operation for the early years of the program with the intent of lowering the funding requirements during the early years. Later activities use a permanent facility as in the L option.
  - B. L - Uses a permanently manned facility for all activities.
2. LG options
  - A. LG1 - All construction activity is done at LEO and those items that require GEO are transported there after construction.
  - B. LG2 - Construction is done at LEO and GEO. Those items that operate at LEO are constructed at LEO; those items that operate at GEO are constructed at GEO.
3. G options
  - A. G - Uses a permanently manned facility at GEO.
  - B. G' - Uses a sortie-mode in GEO in the early years of the program to lower funding requirements, with very limited accomplishment during the initial period (similar to the GEMINI program).

In Part 2 of the study, these options were examined to determine the Space Construction Base requirements for each option, based on the synthesis of the Objective Element requirements included in that option. This section of the PRD describes the options and the results of the study.

The Objective Elements accommodated by each option are shown in Table 3-1.

Table 3-1  
OBJECTIVE ELEMENT ACCOMMODATION

Objective Element	Program Option					
	L'	L	LG1	LG2	G	G'
Solar Power Satellite						
SPS Test Article 1 (TA-1)	X <sup>(1)</sup>	X	X	X	X	X
SPS Test Article 2 (TA-2)	X	X	X	X		
SPS Test Article 3 (TA-3)			X	X		
Space Processing						
Bioprocessing - Urokinase	X <sup>(1)</sup>	X	X	X		
Ultra-pure Glasses - Fiber Optics Preform	X <sup>(1)</sup>	X	X	X		
Shaped Crystals - Silicon Ribbon	X <sup>(1)</sup>	X	X	X		
Earth Services						
30 Meter Radiometer	X <sup>(1)</sup>	X	X	X		
100 Meter Radiometer			X	X		
300 Meter Radiometer			X	X		
Multi-Beam Lens Antenna			X	X	X	X
Phased Array Antenna			X	X		
Multidiscipline Laboratory	X	X	X	X	X	X <sup>(2)</sup>
Living and Working in Space	X	X	X	X	X	X <sup>(2)</sup>
Space Cosmology			X	X		
Sensor Development	X	X	X	X	X	X <sup>(2)</sup>

(1) Shuttle-tended mode

(2) Sortie-mode operation, limited accomplishments

## OPTION L'

This option is accomplished in low earth orbit. It makes use of a shuttle-tended mode of operation for some of the early activities, with later growth to a permanently manned operation.

1. Objectives/Objective Elements - Option L' includes as Objective Elements:

SPS TA-1\*

SPS TA-2

Space Processing Process Development\*

Space Processing Process Optimization

Urokinase

Fiber Optics Class

Silicon Ribbon

Earth Services

30-m Radiometer\*

Multidiscipline Laboratory

Living and Working in Space

Sensor Development

\*These items are accomplished in a shuttle-tended mode. The remaining activities are accomplished in a permanently manned facility.

2. Orbit Regime/Location - This suboption is limited to low earth orbit, nominally 28.5-degree inclination at 400-km altitude, with the exception of SPS TA-1, which is deployed unmanned to geosynchronous orbit after construction and test in low earth orbit.
3. Space Construction Base Description - In the shuttle-tended mode, the Space Construction Base consists of a fabrication and assembly facility with habitation and other accommodations provided by the Shuttle Orbiter. A crew of 3 to 7 is indicated for this phase. After the shuttle-tended activities are completed, the construction base

would be made up of a fabrication and assembly module, power module, core module, habitation module, and laboratory module, as required to accomplish the objective elements listed in Table 3-1. During this phase, a maximum crew of approximately 21 may be required.

4. Transportation - All elements of this suboption will be transported to low earth orbit by the Shuttle Orbiter vehicle. During the shuttle-tended portion of this option, the Orbiter will visit the Space Construction Base periodically and stay docked to the base for up to 30 days at a time to provide crew habitation and other support. Resupply and logistics flights will be accomplished by the Orbiter on a 90-day cycle during the permanently manned periods. The SPS TA-1 will be transported to GEO by an orbital transfer vehicle (OTV).
5. Schedule - A typical schedule for accomplishment of Option L' activities is given in Figure 3-1. This is a representative schedule for this option, but it is anticipated that variations will occur as a result of configuration alternatives.



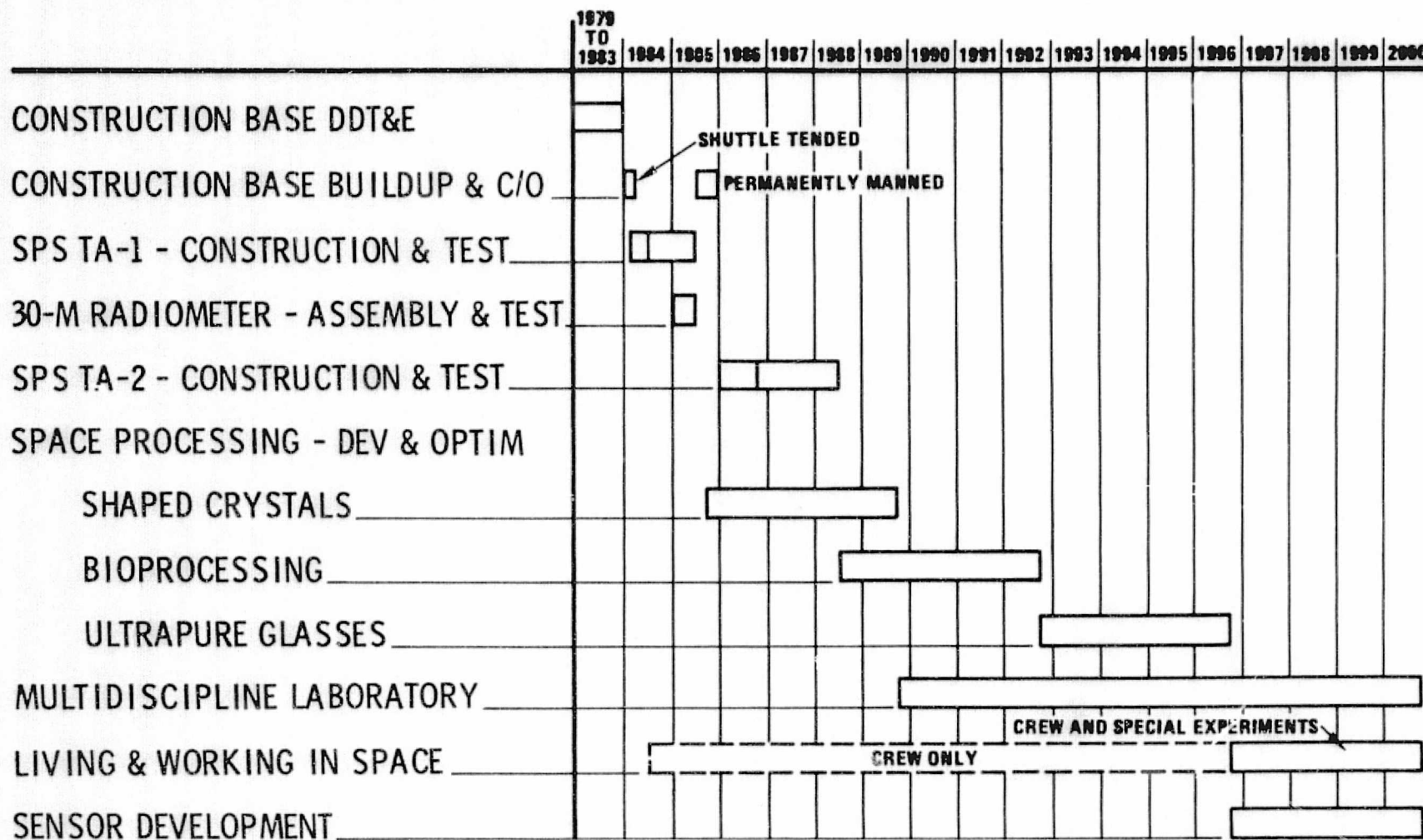


Figure 3-1. Option L'-Typical Schedule

## OPTION L

This option is accomplished in a permanently manned orbital facility located in low earth orbit.

1. Objectives/Objective Element - Option L includes as Objective

Elements:

SPS TA-1

SPS TA-2

Space Processing Process Development

Space Processing Process Optimization

Urokinase

Fiber-Optics Glass

Silicon Ribbon

Earth Services

30-m Radiometer

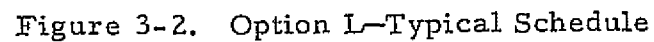
Multidiscipline Laboratory

Living and Working In Space

Sensor Development

2. Orbit Regime/Location - This suboption is limited to low earth orbit, nominally 28.5-degree inclination at 400-km altitude, with the exception of SPS TA-1 which is deployed unmanned to GEO after construction and test in low earth orbit.
3. Space Construction Base Description - The Space Construction Base consists of a fabrication and assembly module, power module, core module, habitation module, and laboratory module as required to accomplish the Objective Elements listed in Table 3-1.
4. Transportation - All elements of this suboption will be transported to orbit by the Shuttle Orbiter vehicle. Resupply and logistics support will be accomplished by the Orbiter on a 90-day cycle. The SPS TA-1 will be transported to GEO by an Interim Upper Stage (IUS).

5. Schedule - A typical schedule for accomplishment of Option L activities is shown in Figure 3-2. Variations in this schedule may occur because of configuration alternatives.
6. Requirements - The requirements that are imposed on the Space Construction Base by the Option L activities are summarized in Table 3-2. These requirements were synthesized by taking the individual requirements of the Objective Elements accomplished in Option L and combining them into an integrated set of requirements for the Space Construction Base so that the base can perform all the option activities.



## OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

a)	Vehicle orbital life	10 years
b)	Resupply period	90 days
c)	Crew size (initial)	7
	(final)	14
d)	Number of modules (initial)	6
	(final)	8
e)	Power level (avg.)	
	- Bus (initial - EOL)	24 kW
	(final - EOL)	64 kW
f)	Pressurized volume (initial	110 m <sup>3</sup>
	for objectives only (final)	600 m <sup>3</sup>
g)	Mass (initial	24,000 k
	of objectives only (final)	50,000 k
h)	Orbital altitude	445 km
i)	Orbital inclination	28°
j)	Vehicle orientation	All axes

a)	Environmental control	
-	Heat rejection (initial)	59 kW
	(final)	168 kW
-	Cabin atmosphere	O <sub>2</sub> /N <sub>2</sub>
-	Pressure	10.13 N/cm <sup>2</sup>
-	Humidity	60% max at 6°C
-	Temperature	18 to 27°C
-	CO <sub>2</sub> level	0.10 N/cm <sup>2</sup> (7.6 mm Hg) max
-	PO <sub>2</sub>	2.14 N/cm <sup>2</sup>
b)	Guidance and navigation	
-	Stability	±0.1 deg
-	Stability rate	±0.05/deg/sec
-	Pointing accuracy	±0.05 deg
-	Position accuracy	±0.5 km

Table 3-2 (Page 2 of 6)

## OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

c) Power	
- Reactant supply* (initial)	1251 kg
(final)	2500 kg
- Bus voltage/frequency (VDC)	28 $\begin{smallmatrix} +3 \\ -2 \end{smallmatrix}$
(VAC)	110 $\begin{smallmatrix} +10 \\ -5 \end{smallmatrix}$ / 400 $\pm 10$ Hz
d) Information management	
- Voice channels (initial)	8
(final)	12
- TV channels (4.5 MHz)	2
- Satellite/Orbiter channels	5 to 20
- Uplink data rates	4 to 10 kbps
- Downlink data rates	10 to 50 Mbps
- Bus rate	2 to 10 Mbps
- Number of control stations	2 + auxiliary
- Processing rate	As required
- Main memory capacity	(distributed
- Auxiliary memory capacity	system)
e) Crew	
- Number of shifts	2
- Hours/shift	10
- Skill requirements	Electrical technician, mechanical technician, electrical engineer, optical engineer, sensor engineer, material scientist, behavioral scientist, physicist
- EVA duration	3 hr/day/crewman
- EVA's/day	2/crewman
- Suit pressure	2.75 N/cm <sup>2</sup>
3. Mission Support Equipment	
a) Crane	
- Mass handling capability	25,000 kg
- Reach	35 m

\*Assumes two weeks (subsystems only)

Table 3-2 (Page 3 of 6)

OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

- Degrees of freedom	Crane body (yaw), shoulder joint (pitch & yaw), elbow joint (pitch), wrist joint (pitch, yaw, roll)
- Arm tip force capability	9 kgF
- Safety provisions	Collision avoidance, torque override, automatic joint lock on motor failure
b) Control station (backup)	
- Volume	77 m <sup>3</sup>
- Mass	5400 kg
- Positions/station required	2
Position functions	Traffic/communications control mission operations/ subsystem control, satellite control, crane control
c) Support shops	
- Volume	77 m <sup>3</sup>
- Mass	5400 kg
- Function	Bench maintenance (LRU, SRU replacement and recalibration)
d) Data laboratory	
- Volume	56 m <sup>3</sup>
- Mass	4100 kg
- Function	Data processing and recording
e) EVA support station	
- Volume	77 m <sup>3</sup>
- Mass	5400 kg
- Functions	EVA suit/tool storage, suit reconditioning
- Airlock capability	Facilities for 2 crewman plus 1 assistant
f) Berthing stations	
- Quantity	TBD
- Volume/station	22 m <sup>3</sup>
- Function	Resource supply, interface monitor

Table 3-2 (Page 4 of 6)

## OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

g) Robots for automated assembly	
- Quantity	2
- Volume	TBD
- Mass	TBD
- Degree of freedom	6
- Average power	TBD
h) Alignment equipment for construction	
- Type	Laser
- Accuracy	0.1 mm
- Mass	TBD
- Volume	TBD
- Average power	TBD
i) Composite Tube Fabrication Module (for construction)	
- Quantity	1
- Diameter	TBD
- Length	8 to 12 m
- Mass	TBD
- Average power	TBD
j) Biologicals Processing Module	
- Volume	175 m <sup>3</sup>
- Mass	11,500 kg
- Peak power	8 kW
- Average power	4 kW
- Compartments	4 (separate environment controls)
- Special requirements	o Centrally located process work station o Foldout equipment bays o Crew washdown station
- Expendable mass	3 kg/day
- Expendable volume	TBD m <sup>3</sup> /day
- Cleanliness class	100,000 + sterile
k) Ultrapure Glass Processing Module	
- Volume	175 m <sup>3</sup>
- Mass	14,500 kg
- Peak power	30 kW



Table 3-2 (Page 5 of 6)

## OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

- Average power	20 kW
- Compartments	2
- Special requirements	<ul style="list-style-type: none"> <li>o Emergency isolation of processing compartment</li> <li>o Centrally located furnaces</li> <li>o Thru-access services</li> </ul>
- Expendable mass	3 kg/day
- Expendable volume	TBD m <sup>3</sup> /day
- Cleanliness class	10, 000
1) Shaped Crystal Processing Module	
- Volume	222 m <sup>3</sup>
- Mass	14, 500 kg
- Average power	12 kW
- Peak power	18. 5 kW
- Compartments	2
- Special requirements	<ul style="list-style-type: none"> <li>o Processing compartment emergency isolation</li> <li>o Thru-access servicing tunnels</li> <li>o Ribbon processor centrally located</li> </ul>
- Expendable mass	10 kg/day
- Expendable volume	0. 01 m <sup>3</sup> /day
- Cleanliness class	10, 000
m) General Purpose Laboratory for MDL	
- Volume	121 m <sup>3</sup>
- Mass	35, 200 kg
- Average power	12 kW
- Special requirements	TBD
- Cleanliness class	10, 000
- Expendable mass	26 kg/day
- Expendable volume	TBD
n) Sensor Development Laboratory	
- Volume	238 m <sup>3</sup>
- Mass	13, 400 kg
- Average power	10 kW

Table 3-2 (Page 6 of 6)

OPTION L SPACE CONSTRUCTION BASE REQUIREMENTS

- Special requirements	Clean laboratory, optical fabrication shop, vacuum laboratory, space porch
- Expendable mass	5.5 kg/day
- Expendable volume	0.5 m <sup>3</sup> /day
- Cleanliness class	100,000
o) Living and Working in Space requirements	
- Volume	3.3 m <sup>3</sup>
- Mass	750 kg
- Average power	1 kW
- Special requirements	2 double/1 single rack
- Expendable mass	1 kg/day
- Expendable volume	8.6 x 10 <sup>-4</sup> m <sup>3</sup> /day
- Cleanliness class	10,000

## OPTION LG1

This option is accomplished with a permanently manned Space Construction Base with elements in both low-earth orbit and geostationary orbit.

1. Objectives/Objective Elements - This option includes as Objective Elements:

- SPS TA-1

- SPS TA-2

- SPS TA-3

- Space Processing Process Development

- Space Processing Process Optimization

- Urokinase

- Fiber-Optics Glass

- Silicon Ribbon

- Earth Services

- 30-m Radiometer

- 100-m Radiometer

- 300-m Radiometer

- Multibeam Lens Antenna

- Phased Array Navigation Antenna

- Multidiscipline Laboratory

- Living and Working in Space

- Sensor Development

2. Orbit Regime/Location - Space construction base elements will be required in low earth orbit (28.5-degree inclination at 400-km altitude) and in geostationary orbit (0-degree inclination at 36,000-km altitude). In this option, all Objective Elements are constructed in LEO and those that require test and evaluation at GEO are transported there after construction. Those activities that are accomplished in low earth orbit and those that are done at geosynchronous orbit are shown in Figure 3-3.

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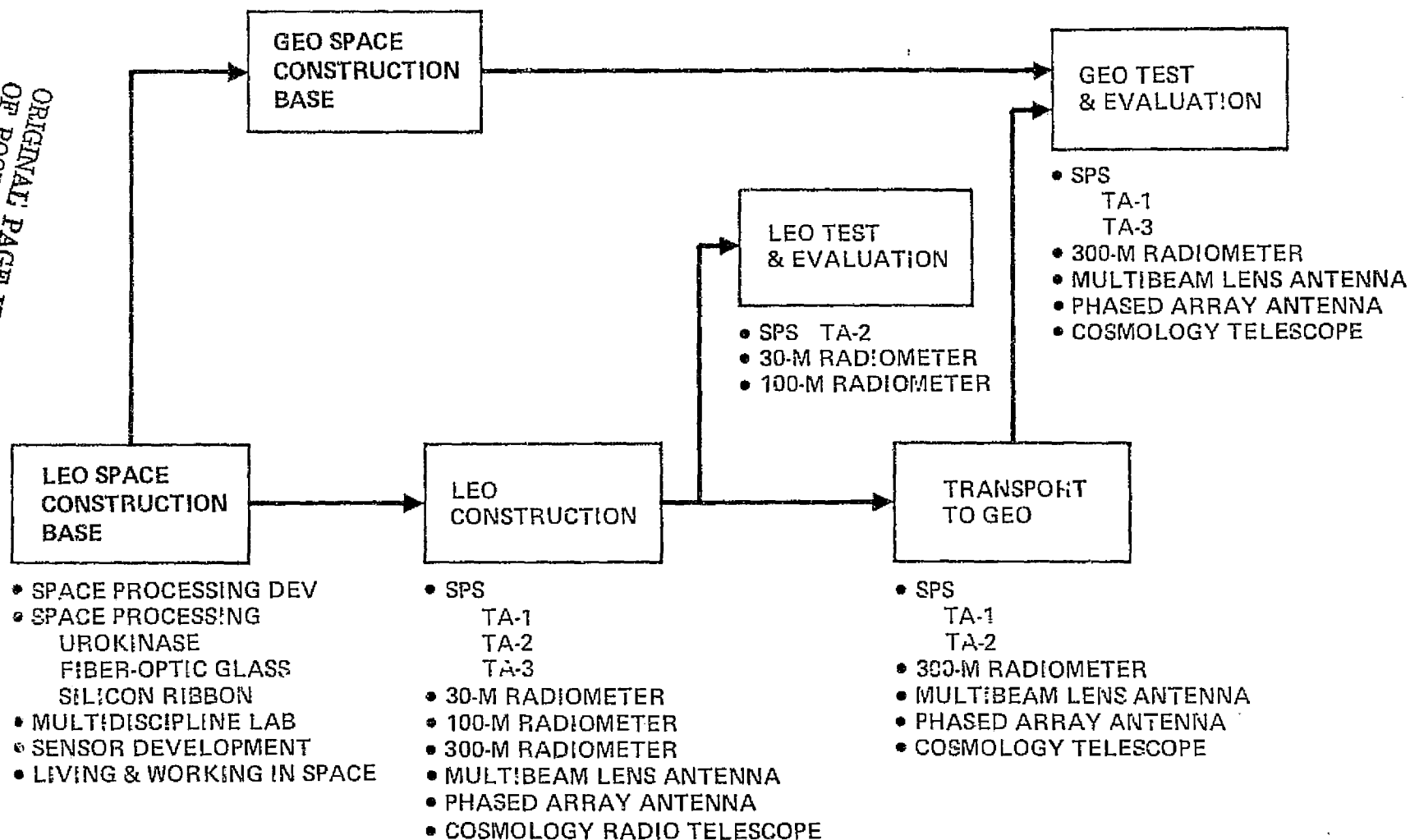


Figure 3-3. Program Option LG1

3. Space Construction Base Description - The LEO Space Construction Base consists of a fabrication and assembly module, a core module, a power module, habitation module, and laboratory module as required to accomplish the LEO activities shown in Figure 3-3. A maximum crew of approximately 30 is indicated for this base. The GEO base consists of a habitation module and support module as required to support evaluation and testing activities at GEO, as shown in Figure 3-3. A crew of 2 to 6 is indicated for the GEO base.
4. Transportation - All elements and material required for this option will be transported to low earth orbit by the Shuttle Orbiter vehicle. Logistics resupply will be accomplished by the Shuttle on a 90-day cycle. The SCB elements that are required at GEO will be transported by an OTV. The mission hardware (Objective Element items) that are required at GEO will generally be transported by an OTV; however, some very large items such as the SPS TA-3 will be self-propelled to GEO.
5. Schedule - The schedule goals for the accomplishment of this option are given in Figure 3-4.

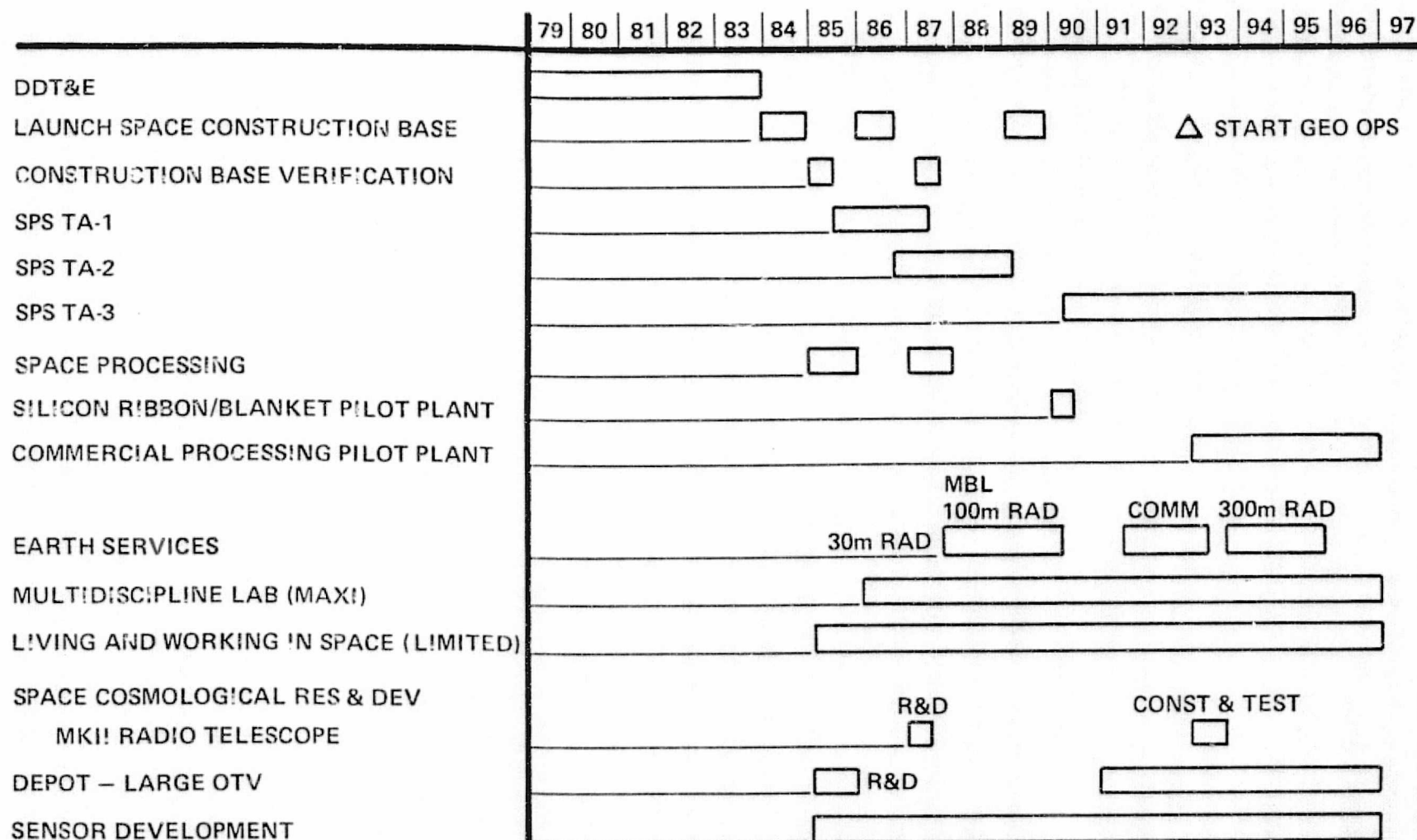


Figure 3-4. Option LG1—Typical Schedule

## OPTION LG2

This option is accomplished with a permanently manned Space Construction Base with elements in both low earth orbit and geostationary orbit.

1. Objective/Objective Elements - This option includes as Objective Elements:

- SPS TA-1

- SPS TA-2

- SPS TA-3

- Space Processing Process Development

- Space Processing Process Optimization

- Urokinase

- Fiber-Optics Glass

- Silicon Ribbon

- Earth Services

- 30-m Radiometer

- 100-m Radiometer

- 300-m Radiometer

- Multibeam Lens Antenna

- Phased Array Navigation Antenna

- Multidiscipline Laboratory

- Living and Working in Space

- Sensor Development

2. Orbit/Regime/Location - Space Construction Base elements will be required in low earth orbit (28.5-degree inclination at 400-km altitude) and in geosynchronous orbit (0-degree inclination at 36,000-km altitude). In this option, the hardware elements that are to operate in LEO are constructed in LEO, and those that are to operate at GEO are constructed at GEO. In one case (the SPS TA-1), the element is required to operate in LEO first and later at GEO; therefore, it is constructed in LEO and later transported to GEO.

Figure 3-5 shows those activities that are done in LEO and those that are done in GEO for this option.

3. Space Construction Base Description - The LEO Space Construction Base consists of a fabrication and assembly module, a core module, a power module, habitation module, and laboratory module as required to accomplish the LEO activities shown in Figure 3-5. A maximum crew of approximately 24 is indicated for the LEO base. The GEO Space Construction Base consists of a fabrication and assembly module, a core module, a power module, and a habitation module as required to support the GEO activities shown in Figure 3-5. A maximum crew of approximately 14 is indicated for the GEO base.
4. Transportation - All elements and material for this option will be transported to low earth orbit by the Shuttle Orbiter vehicle. Logistics resupply will be accomplished by the Shuttle on a 90-day cycle. The Space Construction Base elements and mission hardware that are required at GEO will be transported by an OTV.
5. Schedule - The schedule goals for accomplishment of this option are given in Figure 3-6.



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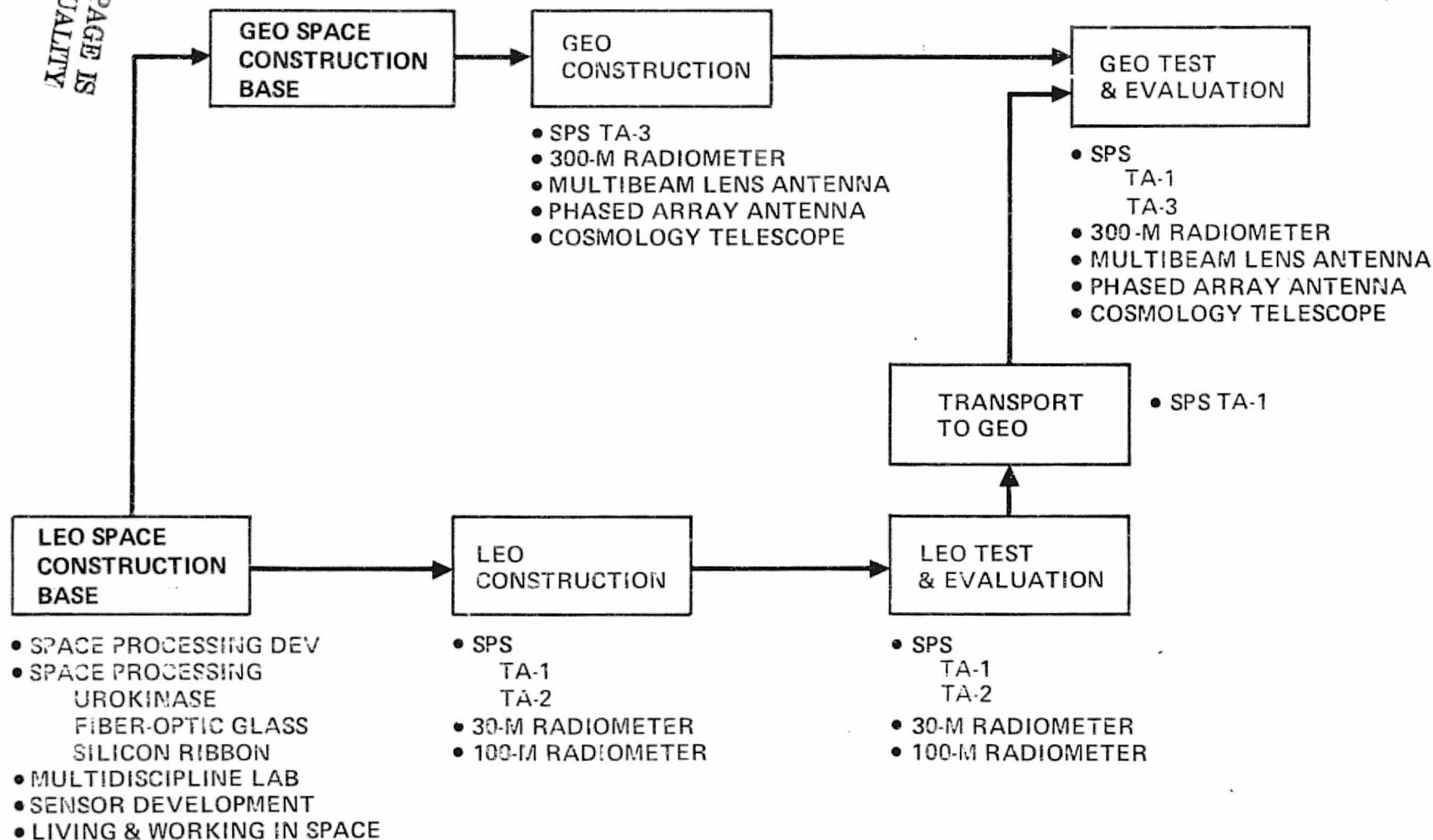


Figure 3-5. Program Option LG2

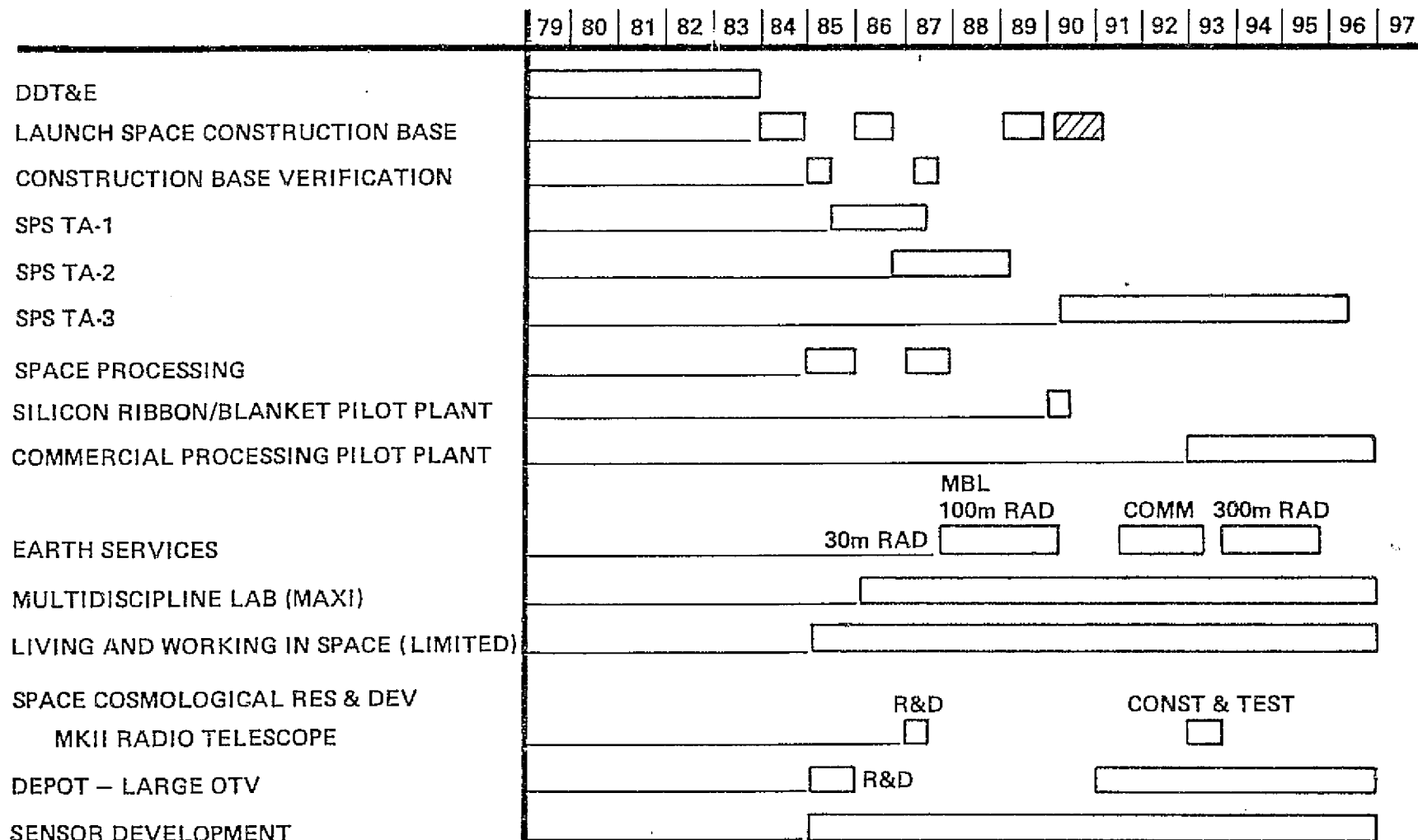


Figure 3-6. Option LG2-Typical Schedule

## OPTION G

This option is accomplished with a permanently manned facility in geostationary orbit (GEO).

1. Objectives/Objective Elements - Option G includes as Objective Elements:
  - SPS TA-1
  - Earth Services
    - ✶ Multibeam Lens Antenna
  - Multidiscipline Laboratory
  - Living and Working in Space
  - Sensor Development
2. Orbit Regime/Location - This option uses a 36,000-km altitude circular orbit with an inclination of 0 degrees. Low earth orbit is used as a staging point to transfer cargo and personnel from the STS to OTV's for shipment to geosynchronous orbit.
3. Space Construction Base Description - The Space Construction Base consists of a fabrication and assembly module, power module, core module, habitation module, and laboratory module in geostationary orbit as required to accomplish the Objective Elements of this option. No permanent elements are in low earth orbit.
4. Transportation - All elements of Option G are transported to low earth orbit by the STS, then to geostationary orbit by orbit transfer vehicles. Resupply and logistics support will be accomplished by the STS on a 90-day cycle.
5. Schedule - The schedule goals for this option are given in Figure 3-7.

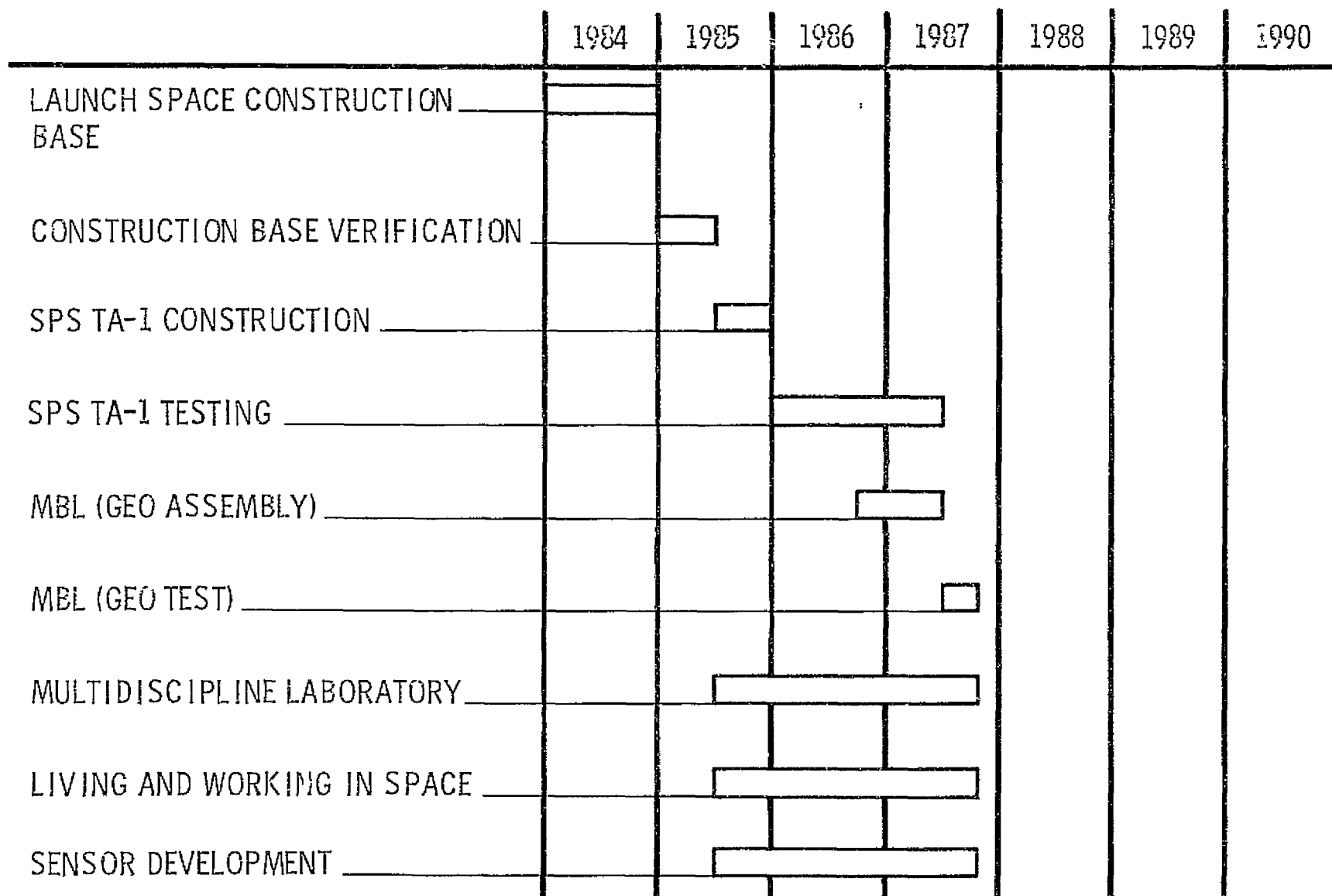


Figure 3-7. Option G—Typical Schedule

## OPTION G'

This option is accomplished entirely in geostationary orbit (GEO) using a sortie-mode in the early years, with later growth to a permanently manned GEO facility.

1. Objectives/Objective Elements - Option G' includes as Objective Elements:

- SPS TA-1
- Earth Services
  - Multibeam Lens Antenna
- Multidiscipline Laboratory
- Living and Working in Space
- Sensor Development

The sortie-mode of operation in the early years may result in very limited capability for some of these Objective Elements.

2. Orbit Regime/Location - This option uses a 36,000-km altitude circular orbit with an inclination of 0 degrees. Low earth orbit is used as a staging point to transfer cargo and personnel from the STS to OTV's for shipment to geosynchronous orbit.
3. Space Construction Base Description - The Space Construction Base for the sortie-mode operation consists of a single module attached to the orbital transfer vehicle. This module contains the necessary habitability support equipment for the crew and the additional facilities required to accomplish the objectives to a minimum level. After growth to a permanently manned facility, the GEO facility will consist of a fabrication and assembly module, power module, core module, habitation module, and laboratory module as required to accomplish the Objective Elements. No permanent elements are in low earth orbit.
4. Transportation - All elements of Option G' are transported to low earth orbit by the STS, then to geostationary orbit by orbital transfer vehicles (OTV's). During the sortie-mode operation, a 30-day cycle

is envisioned for each sortie to GEO, with a concomitant STS resupply flight from the ground. After growth to a permanently manned GEO station, a 90-day resupply cycle is indicated using the STS from the ground to LEO and the OTV from LEO to GEO.

5. Schedule - The schedule goals for this option are given in Figure 3-8.

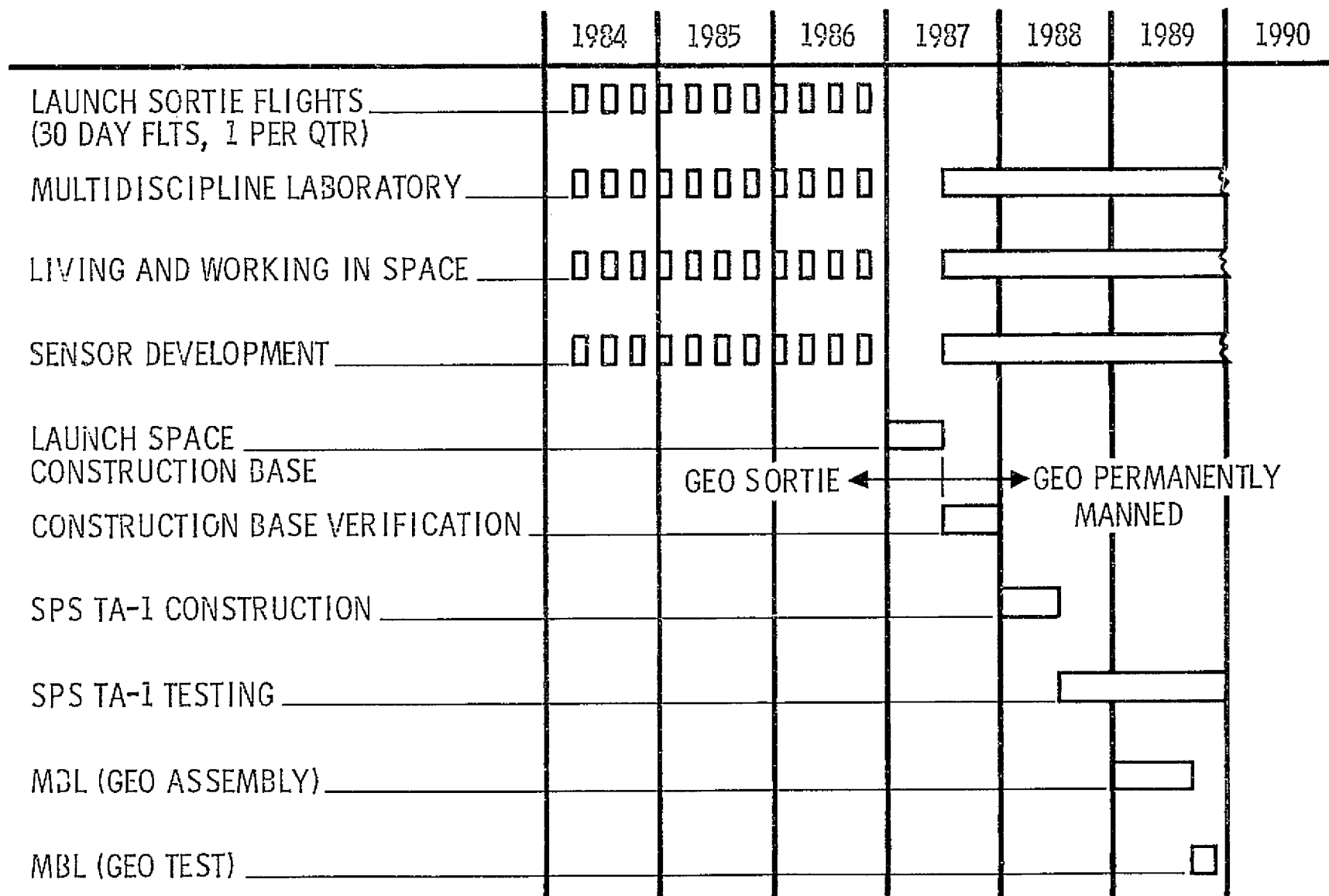


Figure 3-8. Option G'—Typical Schedule  
(With Shuttle-Tended (GEO Sortie) Operations)